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Study for the analysis of intermodal processes using simulation techniques

Report

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POLITECNICO DI TORINO

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1. INTRODUCTION

The present work is written by Anna Rupérez Navarro, Chemical Engineer by Universitat Politècnica de Catalunya, currently working as Data Analyst in Milan (Italy).

The topic of the thesis is proposed by Universitat Politècnica de Catalunya professor, Antoni Guasch Petit, and it is supervised by Politecnico di Torino professor, Arianna Alfieri. It is part of the Double Master's Degree in Engineering Management between Universitat Politècnica de Catalunya (UPC) and Politecnico di Torino.

The interest for this work comes from the course "Simulation of Industrial and Logistic Systems" held by professor Antoni Guasch during the first part of the Double Master's Degree at UPC. During the course I have discovered the large and interesting world of industrial logistic processes simulation and its large range of economic and environmental implications.

The tool used during the course was *Arena Simulation Software*, different from *FlexSim Software,* the one used in the present work. Neither the UPC professor or I had experience regarding the *FlexSim*, therefore, this has been the main difficulty of this work and has limited the scope of the simulation.

However, the possibility to learn a new simulation tool, my strong interest on logistics topics, the growing socio-political interest in the Mediterranean Corridor and the settled potential of Barcelona (my home city) as a logistic hub, made me choose this topic as my Final University Examination.

The present work is a merge of conceptual topics such as the Mediterranean Corridor, EU investments, Barcelona as a centre logistic hub, the Port of Barcelona, a site analysis, the Lohr railway system and the new terminal description. Those mentioned topics are strongly related to the practical part of the thesis, which is the simulation and results discussion.

The work is structured in four main parts: Introduction, Development, Results and Discussion, and Conclusions.

In the present section, Introduction, are explained the general and simulation objectives, as well as the simulation scope and requirements.

1.1. GENERAL OBJECTIVE

The main objectives of the thesis are the definition, analysis, simulation and results interpretation of a new railway intermodal terminal in Barcelona inside the context of the Mediterranean Corridor.

In the present work it is documented the current situation of the European Railway Corridors (with a special zoom in the Mediterranean Corridor), are analysed the factors that make Barcelona a referent logistics centre, is analysed the location of a new railway intermodal terminal, is described the new terminal and its main components, is defined the logistic process through a set of diagrams, and finally, the new terminal is simulated using *FlexSim* and collected statistics and results are discussed.

Together with professor Antoni Guasch, we have specified the scope of each part, agreeing that the focus is not the level of detail added back in each part, but the link of interconnected topics that come in touch when simulating a new intermodal terminal.

1.2. SIMULATION OBJECTIVE

The globalization of world economy has led to a constant decrease in the cost of transport. Nowadays many intermodal terminals are still managed without pervasive support of information technologies: the terminal management highly relies on well-assessed policies, typical of each terminal, which have been defined by the managers on the basis of their experience.

In most cases these policies are satisfactory since the terminals have sufficient resources in terms of tracks, equipment, human resources and they can support the current flows of freight. On the other hand, the growth of freight transport shows a rapidly increasing trend in the short and medium terms, which the current infrastructures and management tools cannot meet.

In the present work, a simulation of a new railway intermodal terminal is proposed to understand the impact of the different design parameters and decide which amount of task executers are needed in different scenarios.

The simulated intermodal terminal allows the unload/load (U/L) of semi-trailers (STs) in the set of wagons that form the train. The design and operation of the terminal will be based on the Lohr system (see more in the next sections) that allows the U/L of the STs in a very efficient way.

During the simulation, two scenarios (5 and 8 trains per day) with different amount of task executers are performed in order to study the impact of those in the resulting model.

The simulation's driver has been to reduce the amount of waiting time of the trains on the Waiting Tracks.

The simulation input design parameters are:

- Automated Guided Vehicles (AGVs) and train speed;
- Amount of AGVs;
- Railway inter-arrival times;
- U/L time;

The statistics collected are:

- Average waiting time of the train on the waiting track;
- The maximum content of trains on the waiting track;
- Cycle time for each train;
- AGV's utilization;
- Unloaded time for each ST;
- Amount of STs in the system (WIP);

Therefore, the railway model simulation performed in the present work has strong analytic content, and, at the same time, creates a 3D simulation base for a new railway terminal based on Lohr system.

1.3. SIMULATION SCOPE

The simulation performed during this work is a simplified version of reality. It does not take into account all the factors, circumstances and cases implied in the construction of a new rail terminal. This is due to the huge amount of factors and design parameters that come in touch when simulating a railway terminal.

Those non-simulated variables have been determined as "out of scope" together with Antoni Guasch professor's supervision.

The variables that are "out of scope" and are not an aim of the simulation but are mentioned and described along the present work are:

- Parking capacity;
- STs parking needs;
- Control gate;
- Expected distribution of truck arrivals for the Delivery/Collection of STs;
- The interaction of trucks and AGVs in the road network.

Note that the design values set to perform the simulation are estimated values or real values found on different sources and agreed together with Antoni Guasch professor.

1.4. SIMULATION REQUIREMENTS

In order to perform the practical part of this work, it is required to simulate through a logistics software.

A simulation is an abstraction of a real system using a software tool. It is not about finding exact results, but about reaching a good approximation. Therefore, the model simulation is a simplified representation of a real system portion.

The benefits of simulating are the following:

- To analyse and make decisions about complex systems composed by interdependent variables and randomness;
- To study the impact of the variables;
- To try changes before their implementation in the real system;
- To determine system requirements: the amount of AGVs, operators, machines, etc.;
- To train;
- To correct errors in the system before implementing it, which implies a reduction on the economic and environmental costs.

The 3D simulation software used to model the new rail terminal is *FlexSim Software*, version 2018.2.2 (see Figure 1-1).

With *FlexSim* is possible to model, simulate, predict and visualize systems in manufacturing, material handling, healthcare, warehousing, mining, logistics, etc. [1]

It is a powerful and user-friendly tool proposed by UPC professor, Antoni Guasch, that allows to gather statistics and, at the same time, create great 3D animations.

This last characteristic is the differentiating element of *Flexsim* tool in comparison with another known software, *Arena Software*, already seen during the Double Master's Degree.

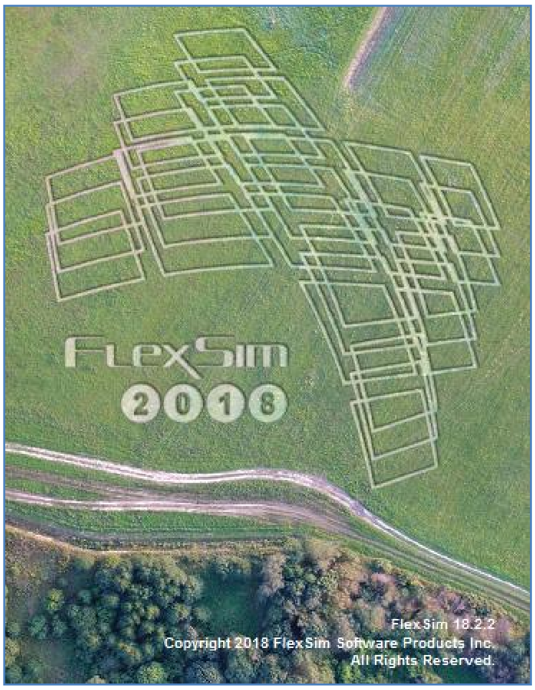

Figure 1-1 FlexSim Software 2018, loading banner

However, the acquired *FlexSim* students license has a limitation of 100 objects per model that had difficult the creation of the simulation model.

2. DEVELOPMENT

2.1. EUROPEAN RAIL FREIGHT CORRIDORS

In October 2011, the European Commission presented the new network of 10 priorities to be achieved by 2030, the "Core Network Europe". It will connect the European metropolitan capitals, the regions, the hubs and the ports, allowing efficient commercial exchanges, fast mobility of people between European countries and contributing to the objectives EU CO_2 reduction.

In the last few decades, the need for faster and more efficient transport has been combined with the requirement to protect the environment reducing pollution. The EU has focused on the implementation of the TEN-T[1] network, the metropolitan railway of Europe, which provides for 9 corridors to rapidly, efficiently, and sustainably connect the continent across 17,500 km of tracks connecting ports, airports, interports and large urban centers.

'Freight Corridor', according to Article 2.2.a of EU Regulation No. 913/2010 [2], means all designated railway lines, including railway ferry lines, on the territory of or between Member States, and, where appropriate, European third countries, linking two or more terminals, along a principal route and, where appropriate, diversionary routes and sections connecting them, including the railway infrastructure and its equipment and relevant rail services.

2.1.1. Rail freight: efficient and environmentally friendly

Rail freight transport is resource-efficient and environmentally friendly and helps mitigate congestion on road networks. The European Union has the transport policy objective to shift freight transport from road to rail.

Rail freight is particularly competitive for long-distance transports. However, the competitiveness of rail for cross-border flows is still severely hampered by historic obstacles including, first and foremost, diverging technical, regulatory and operational standards.

Up to now, the liberalization and harmonization of the European rail freight markets were not sufficient to make rail freight competitive relative to other means of transport.

2.1.2. The concept of Rail Freight Corridors (RFC)

To support the set-up of a European rail network for competitive freight transportation, the European Parliament and the EU Council adopted Regulation No. 913/2010. The regulation paves the way for the establishment of trans-European Rail Freight Corridors

[1] TEN-T, Trans-European Transport Network is a European Commission policy directed towards the implementation and development of a Europe-wide transport network.

connecting at least three EU member states. Moreover, it stipulates the establishment of an administrative structure which engages all stakeholders in extensive cooperation and facilitates the harmonization of technical, operational and organizational regulations. A Corridor One-Stop-Shop (C-OSS) will be set up for each corridor as the single point of contact.

Within the EU there are currently nine rail freight corridors, which in geographical terms coincide with the TEN-T core network corridors. The establishment of additional corridors is currently under review.

2.1.3. The White Paper on Transport: Rail Freight 2050

The European Commission adopted a roadmap, The White Paper, of 40 concrete initiatives for the next decade to build a competitive transport system that will increase mobility, remove major barriers in key areas and fuel growth and employment. At the same time, the proposals will dramatically reduce Europe's dependence on imported oil and cut carbon emissions in transport by 60% by 2050.

Focusing on rail freight, the White Paper key goals include: [3]

- Greater use of more energy (efficient modes): 30% of road freight over 300 km should shift to other modes by 2030, and more than 50% by 2050;
- Rail freight almost doubled: +360 billion ton-km (+87%) compared to 2005;
- By 2050, connect all seaports to the rail freight system;

2.1.4. Regulation No. 913/2010

The Regulation (EU) No. 913/2010 concerning a European rail network for competitive freight became effective on 9 November 2010. To this end, the Regulation sets modalities and timing by which the national network operators are to coordinate the corridor implementation.

Main measures contained in the Regulation include: [4]

- Implementation of the subsystems for the interoperability of corridors in order to allow the passage of trains from one national network to another without encountering technical barriers;
- Coordination investments in order to implement the TSI (Technical Specifications for Interoperability) railway standards on all lines relating to the corridor;
- Publication and updating of Implementation Plans for each corridor describing main corridor's features such as the reference transport market, bottlenecks, investment and procedures for traffic management to be put in place in order to improve the rail freight competitiveness;
- Creation of a corridor body known as Corridor One-Stop-Shop in charge of the publication and the allocation of the capacity for international rail freight transport;

- Creation of prearranged paths harmonized among Corridor Infrastructure Managers to promote rail freight transport;
- Performance monitoring of freight trains and customer satisfaction through monitoring systems.

The Regulation required Member States to establish international market-oriented Rail Freight Corridors (RFCs) in order to meet three main challenges [5]:

- Strengthening co-operation between Infrastructure Managers on key aspects such as the allocation of paths, deployment of interoperable systems and infrastructure development
- Finding the right balance between freight and passenger traffic along the RFCs, giving adequate capacity for freight in line with market needs and ensuring that common punctuality targets for freight trains are met
- Promoting intermodality between rail and other transport modes by integrating terminals into the corridor management process

Is in this context that the present work acquires importance, because traffic does not usually start and end on a RFC exclusively but in other transport modes. Therefore, efficient and harmonised interfaces to the existing processes and tools are needed.

The EU Regulation defines the following corridors for the creation of the European rail network for competitive freight:

- Scandinavian-Mediterranean
- North Sea-Baltic
- North Sea-Mediterranean
- Baltic-Adriatic
- Orient-East Med
- Rhine-Alpine
- Atlantic
- Rhine-Danube
- Mediterranean

A map of the nine Rail Freight Corridors running through Europe is shown below in Figure 2-1.

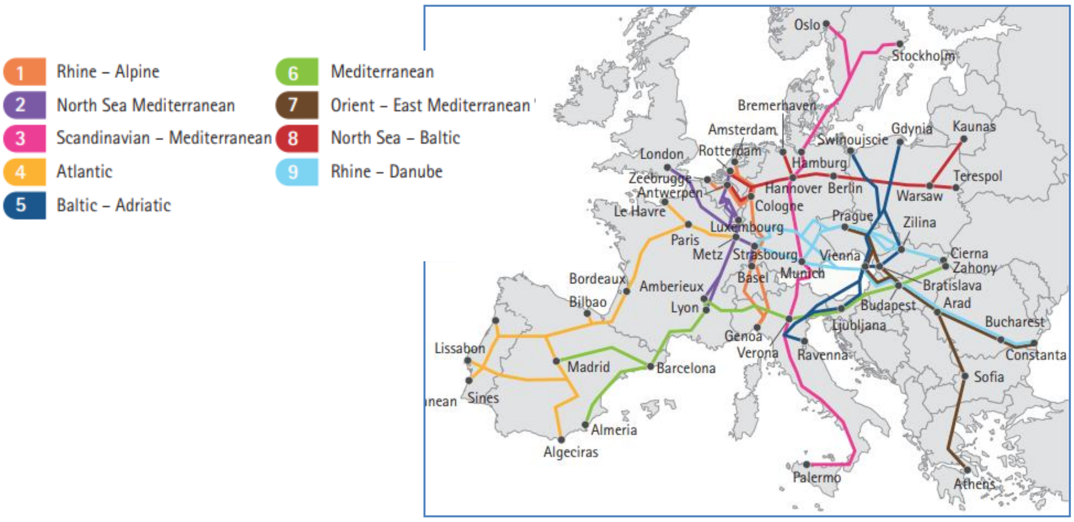

Figure 2-1European Rail Freight Corridors [26]

2.1.5. Mediterranean Corridor

The Mediterranean Corridor is the main east-west axis in the TEN-T Network south of the Alps. It runs between the south-western Mediterranean region of Spain and the Ukrainian border with Hungary, following the coastlines of Spain and France and crossing the Alps towards the east, through Italy, Slovenia and Croatia and continuing through Hungary up to its eastern border with Ukraine.

2.1.5.1. Overview

The regions along the Mediterranean Corridor represent an important socio-economic area within the EU. With 18% of the EU's population, the Corridor regions generated 17% of the EU's GDP. [6]

Economically speaking the most important regions of the Corridor are the Lombardy, the Rhone-Alpes region, Catalonia and Madrid.

The corridor primarily consists of road and rail, aside from the Po River, several canals in Northern Italy and the Rhone River from Lyon to Marseille. The corridor is over 6.000 km long; it will provide a multimodal link for the ports of the Western Mediterranean with the centre of the EU. It will also create an east-west link through the southern part of the EU, contributing to a modal shift from road to rail in sensitive areas such as the Pyrenees and the Alps, and connect some of the major urban areas of the EU with high-speed trains.

See Figure 2-2, a TEN-T interactive map, with the main multimodal links of the ports and airports connected through the Mediterranean Corridor.

Figure 2-2 Interactive map Ten-T [7]

The total length of the Mediterranean Corridor lines in Spain is 3.397km (3.015km of principal route), while in Italy is 861km (636km of principal route).

In Spain, Italy and Hungary 556 km of diversionary routes have been included, for train rerouting in case of disturbance.

Also, more than 90 terminals have been included in Mediterranean Corridor – RFC 6, 37 terminals in Spain and 14 terminals in Italy. In the areas of Barcelona and Turin, the terminals are listed below:

Barcelona Area

Barcelona Can Tunis, Barcelona Morrot, Castellbisbal, CELSA (Castellbisbal), Granollers Terminal, GONVAUTO (Castellbisbal – Barcelona), Martorell, SEAT-Martorell Terminal, SOLVAY (Martorell) and Port of Barcelona.

Turin Area

Sito Interporto di Torino, Orbassano AFA and Orbassano Terminal Intermodale.

See Attachment I for a rail track characteristics table of those mentioned terminals.

2.1.5.2. Main bottlenecks and missing links

According to Article 2 of Regulation (EU) No 1316/2013 [8], bottleneck means a physical, technical or functional barrier which leads to a system break affecting the continuity of long-distance or cross-border flows and which can be surmounted by creating new infrastructure, or substantially upgrading existing infrastructure, that could bring significant improvements which will solve the bottleneck constraints.

The key technical parameters, infrastructure requirements set in Article 39 of Regulation (EU) No 1315/2013, were considered obligatory and common part of the future elements of the transport infrastructure for both passengers and freight transport capacity. [9]

- full electrification of the line tracks and sidings;
- at least 22,5t axle load;
- 100km/h line speed;
- freight trains with a length of 750m;
- track gauge for railway lines 1.435mm.

The most sensitive section of the corridor is the new cross-border rail link between France and Italy (Lyon-Turin). Multimodal connections with ports in Spain and France have to be developed and some railway sections in Italy and France need to be upgraded in order to remove key bottlenecks. The coexistence of two gauges, International Standard gauge (1435 mm) or Iberian gauge (1668 mm), is another challenge for this corridor, as is the full integration of the newest Member State, Croatia.

2.1.5.2.1 Bottlenecks in Barcelona Area

Track gauge

The lack of standard gauge in most of the Spanish sections of Mediterranean Corridor - RFC 6, prevents from dispatching international direct rail freight trains, and forces to car load changing manoeuvres, which penalizes rail transportation competitiveness.

The connection of Barcelona node with French border and the Zaragoza-Madrid-Sevilla branch of the Mediterranean Corridor is in compliance with the International Standard gauge as seen in Figure 2-3 below:

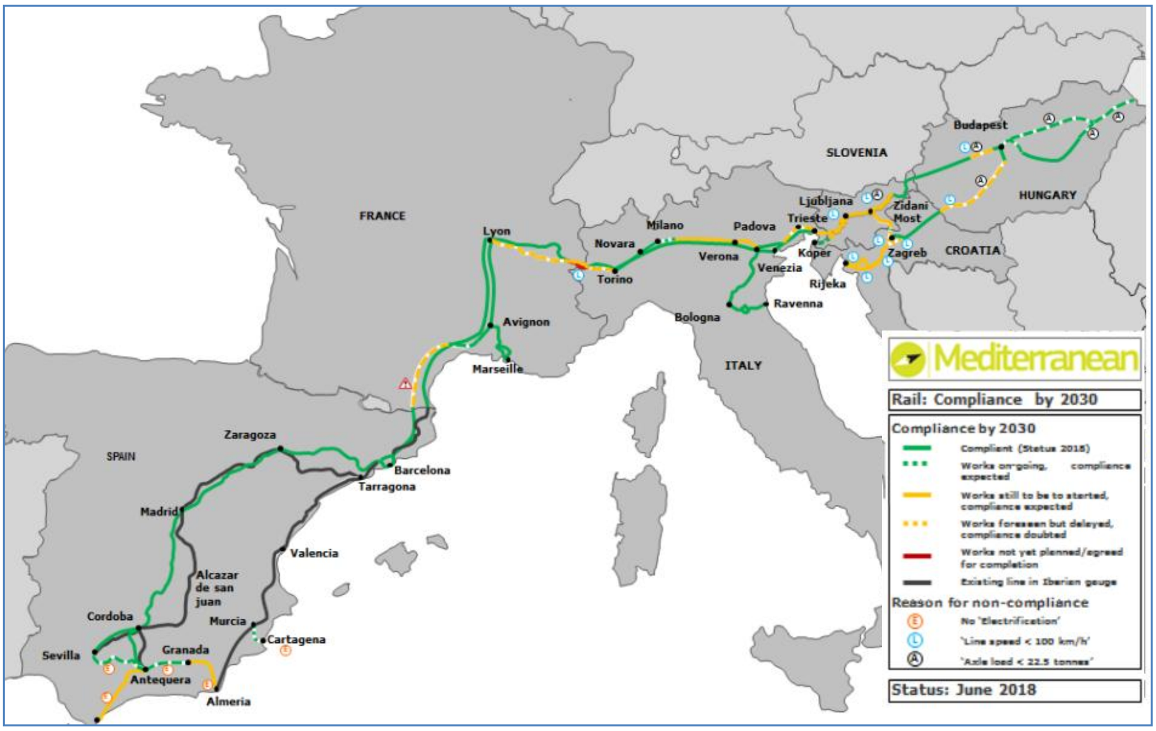

Figure 2-3 Mediterranean Corridor - Rail Compliance by 2030 map. [9]

Regarding the Barcelona-Valencia-Algeciras branch of the Mediterranean Corridor through its pass in Spain, the Spanish Ministry of Development has promised to complete the International Standard Gauge connections of the following nodes by 2021. [10]

See Figure 2-4 for reference, wherein blue colour "Ancho internacional", which means UIC gauge and in red colour "Ancho Iberico", which means Iberian gauge.

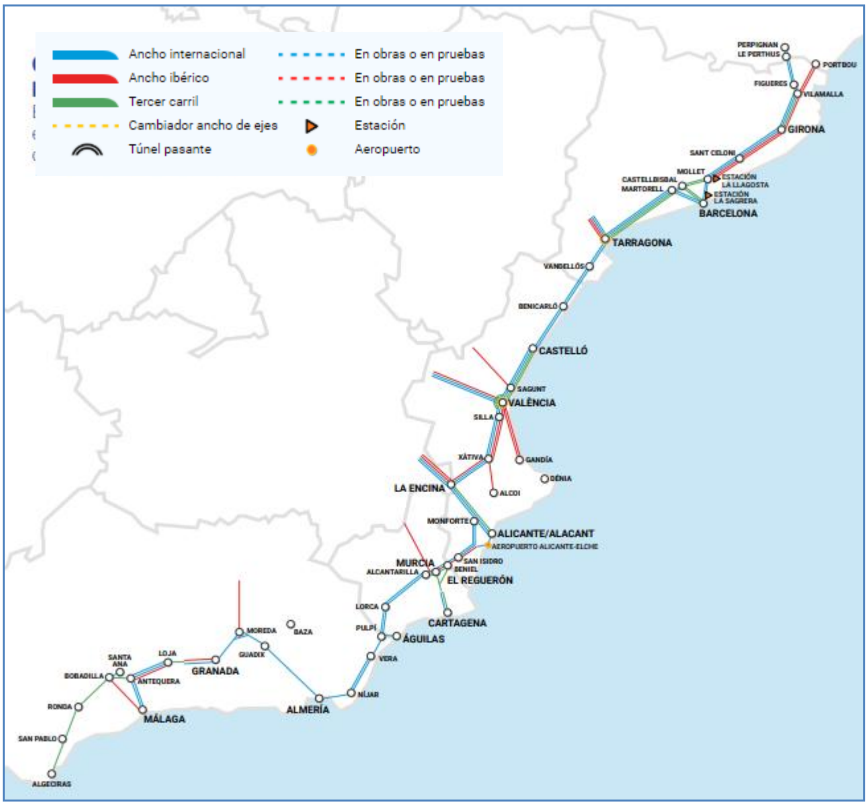

Figure 2-4 Mediterranean Corridor - International gauge connection by 2021. [10]

Maximum train length

Existing limitations to train length (500m - 525m) does not allow, in most of the Spanish corridor, the operation of freight trains with the maximum interoperable length of 750 m, which penalizes rail transportation competitiveness.

Regarding Barcelona Node, train length allowance is both 500m in the Iberian gauge and 750m in the UIC gauge, as seen in Figure 2-5 below.

Figure 2-5 Mediterranean Corridor - Max. Train Lenght. [9]

Lack of capacity in lines

A congestion scenario has been identified in section *Martorell-Castelbisbal* (north-west of Metropolitan Area of Barcelona). See Figure 2-6 for reference.

It is a double track corridor with heavy commuter train traffic. This fact penalizes freight trains, limiting its potential development because the few available windows cannot host competitive paths.

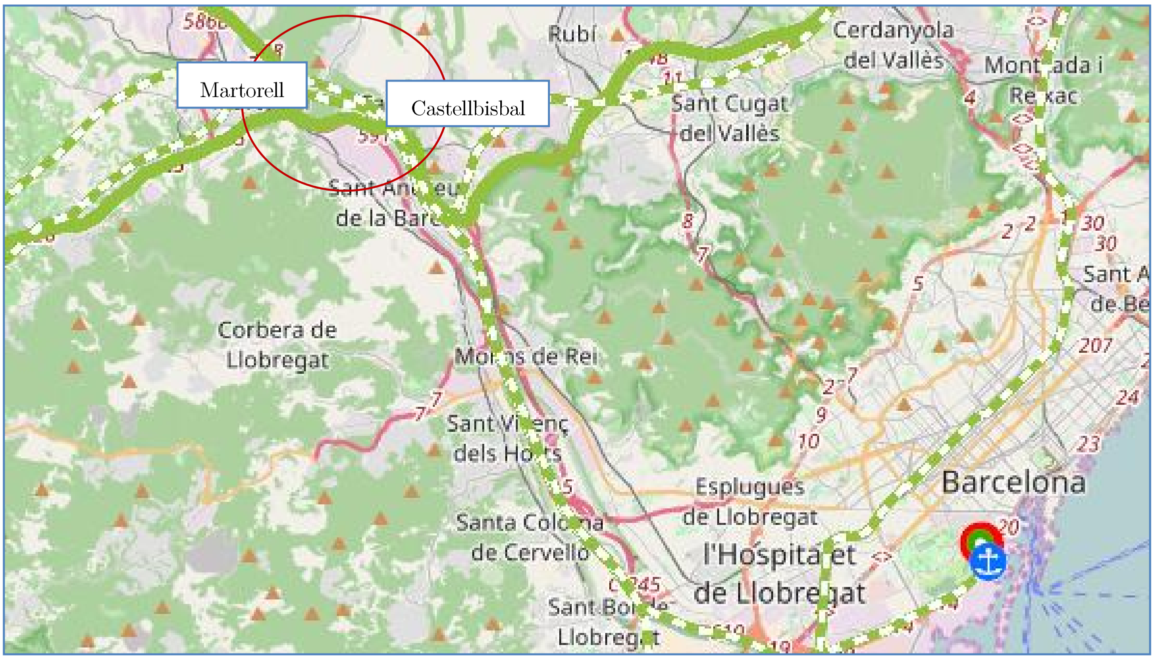

Figure 2-6 Mediterranean Corridor - Martorell-Castellbisbal section. [7]

As a solution, *ADIF*[2] has tendered three contracts of works and supplies for a total of 108 million euro for the implementation of the International Standard gauge in the Mediterranean Corridor in Catalonia.

In a statement, ADIF has informed that the most relevant performance will be the installation of a third track on the way between Castellbisbal and the Martorell-Seat junction to reduce congestion. This new track will be operational by 2020.

Access to Ports and Terminals

Critical investment has been made in Spain to provide International Standard gauge access to some logistics and freight rail facilities along the Corridor (known as "last mile projects"). Anyhow, capacity and performance of these links have shown insufficient to absorb significant traffic growths, like those expected in the Corridor.

[2]ADIF, an acronym of Administrador de Infraestructuras Ferroviarias, is a Spanish state-owned railway infrastructure manager under the responsibility of the Ministry of Development, charged with the management of most of Spain's railway infrastructure.

In 2014 a *Capacity Allocation study on the Mediterranean Corridor - RFC 6* has been carried out to identify the existing bottlenecks, analyse present and future capacity needs and so define priorities for bottlenecks removal. After the identification and description of physical technical and functional bottlenecks, the priority list of bottlenecks was put together in terms of strategic importance "geographical location" in the section, key characteristics, like nature, present vs. future bottlenecks, length, its effects and the rank of priorities.

The Spanish sections have been grouped to ensure continuity of flows in four sections in priority order: French border to Valencia, Barcelona to Madrid, Valencia to Almeria and diversionary lines.

The access to ports and terminals will be adopted to UIC gauge in parallel with the installation of UIC gauge along the corridor.

2.1.5.2.2 Bottleneck in Turin Area

Turin- Lyon line

The new railway link Turin- Lyon (see Figure 2-7), with the 57,5 km Mont Cenis base tunnel as its main part major component, is the main project of the whole Mediterranean Corridor. It is a high-capacity railway line for freight and passengers which stretches over 270 km, of which 70% in France and 30% in Italy.

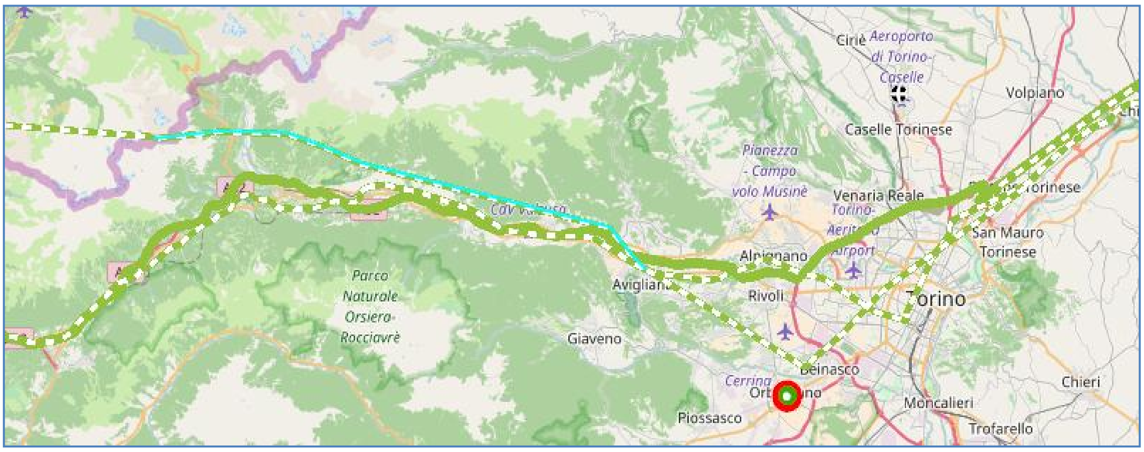

Figure 2-7 Mediterranean Corridor - Avigliana-French Border section. [7]

It is highly strategic because it is the main missing link in the corridor which aims at connecting south-western Europe with Central and Eastern European Countries. Failing this high-performance connection, transport relations would be hampered, especially for the trade between Spain, France and Italy.

It is scheduled that the construction works will last 10 years and the new line will be operational by 2029.

See Attachment I for a rail track characteristics table in Barcelona and Turin Areas.

2.1.5.3. TEN-T/CEF Projects

In the CEF[3] Regulation is included a list of projects pre-identified for possible EU funding during the period 2014 – 2020, based on their added value for TEN-T (Trans-European Transport Network) development and their maturity status. In this section will be discussed the investments required for the development of the corridor infrastructure by 2030 in Barcelona and Turin nodes and their links with TEN-T/CEF Projects.

2.1.5.3.1 Barcelona Node

In all major urban nodes, bottlenecks exist due to the overlapping of different types of rail traffic (metropolitan, regional, long distance and freight). The planned investments are necessary to relax these constraints.

Taking the urban area of Barcelona, for instance: once all major traffic generators will be connected to the rail network, capacity issues in the urban area of Barcelona will arise, with about 100 – 150 freight trains per day on some sections having to share the tracks with heavy commuter rail traffic; this issue would merit a more in-depth analysis of local traffic.

The main necessity for the city would be finishing the construction of the Intermodal Rail Terminal La Sagrera, this will provide high speed, long and short distance to the surrounding areas.

Similarly, the implementation of UIC gauge in La Llagosta terminal would allow a better connection to the Corridor.

Although there is a rail connection with Terminal T2 of the airport, it should be connected with Terminal T1, which is the most used one.

An enhancement of ring roads and accesses of Barcelona is necessary in order to reduce congestion; a fourth ring road would allow for smoother traffic management.

The rail access to the Port of Barcelona has a provisional and limited connection in UIC, producing important operation problems and reducing load capacity. New rail access fully interoperable to connect the southern area of the port with the corridor is a priority.

Regarding the Port of Barcelona, there are one closed and one ongoing TEN-T/CEF projects in the context of "New Southern Road and Rail Access to the Port of Barcelona -Phase I and II", as seen in the Figure 2-8 below.

[3] *CEF, Connecting Europe Facility is a key EU funding instrument developed specifically to direct investment into European transport, energy and digital infrastructures to address identified missing links and bottlenecks.*

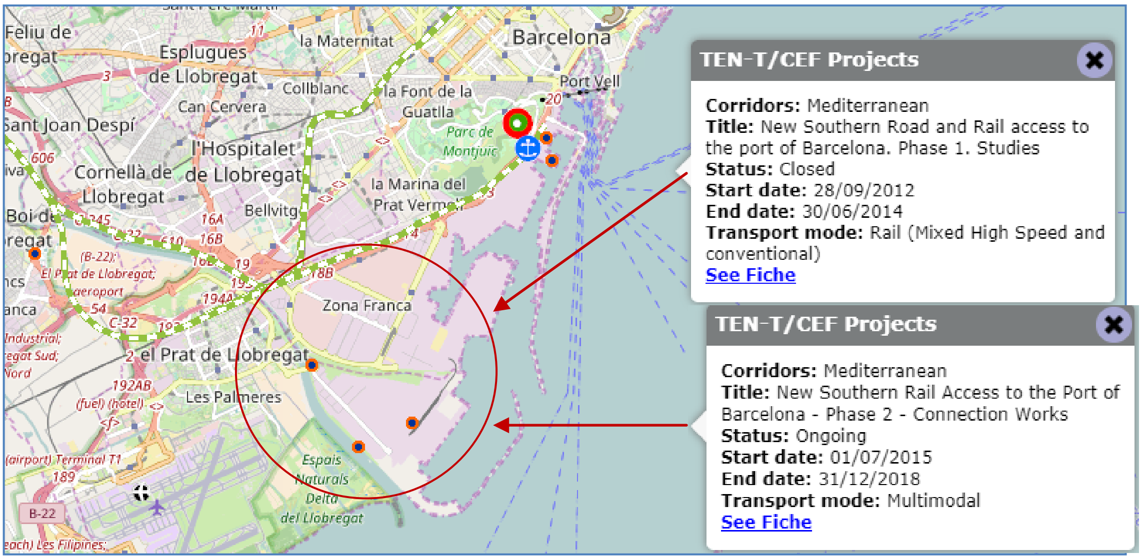

Figure 2-8 TEN-T/CEF Projects in Barcelona Node. [7]

It consists of studies and connection works on the new southern road and railway access to the Port of Barcelona. It aims to carry out the technical assessment of the alternatives, including the planning and final design studies as well as the financial-economic analysis.

It is part of the project aim ensuring the UIC gauge connection between the Port of Barcelona and the French border, as set high-speed rail line between Madrid-Barcelona-French border.

2.1.5.3.2 Turin Node

The Turin Node is an essential point of the national railway system, both concerning its function as a node for the High Speed/High Capacity (HS/HC) system and for the Turin-Lyon Corridor and its metropolitan mobility value.

The current infrastructural organisation of the node does not permit to exploit its potential capacity in terms of rail traffic.

The planned interventions for the Turin Node need to be completed with specific projects to allow the capacity and punctuality increase, due to the overlapping of different types of rail traffic (metropolitan, regional, long distance and freight).

The planned interventions for the node, both infrastructural and technological, are essential in order to increase its capacity and enhance the intermodal integration. In particular, rail projects are foreseen in order to allow better track occupancy and increase the capacity of the node.

For instance, as seen in Figure 2-9 below, the Orbassano node is the first and most urgent action to be implemented by 2027.

Figure 2-9 TEN-T/CEF Project in Turin Node. [7]

2.2. BARCELONA, LOGISTIC HUB OF REFERENCE

Barcelona is the capital and largest city of the autonomous community of Catalonia, as well as the second most populous municipality of Spain. With a population of 1.6 million within city limits [5], its urban area extends to numerous neighbouring municipalities within the Province of Barcelona and is home to around 4.8 million people, making it the sixth most populous urban area in the European Union after Paris, London, Madrid, the Ruhr area and Milan.

It is one of the principal European cities and the centre of a vast metropolitan region of more than 160 towns. It is the economic, cultural and administrative capital of Catalonia and the centre of an emerging area of economic activity in Southern Europe, with 17 million people and 800,000 businesses. [11]

With a long industrial tradition and a dense business fabric, Barcelona has a highly diversified economic structure. Its more traditional sectors coexist with new emerging ones, creating new clusters of knowledge focused on internationalization and innovation.

Barcelona's international economic activities are mainly driven by the Trade Fair, the Port, Airport, Zona Franca Consortium, Barcelona's Tourism Consortium, Barcelona City Council and its new technological innovation districts.

In addition, Barcelona and Catalonia are leading Spain's movement towards a knowledge economy. As such, Catalonia, in 2017, accounted for 21.6% of Spain's innovation-based companies and 22.5% of all Spanish spending on innovation activities.

Regarding this last point, and given the importance of innovation in the promotion of competitiveness, productivity and the internationalization of firms, the logistics industry is one of the key sectors for Barcelona and Catalonia. [11]

The main factors that determine Catalonia's and Barcelona's competitive advantage in the logistics sector are: [11]

2.2.1. A geostrategic location

Catalonia has historically been a transit route between the Iberian Peninsula, North Africa and Europe, and this functionality is seen today in a vocation for logistics with a continental reach.

The geography of Catalonia is articulated along two corridors, one called Ebre and the other the already mentioned Mediterranean (Figure 2-10). This second head towards Europe through La Jonquera and Portbou, an eastern route through the Pyrenees where the topography allows direct access to the plains and inland valleys of Europe.

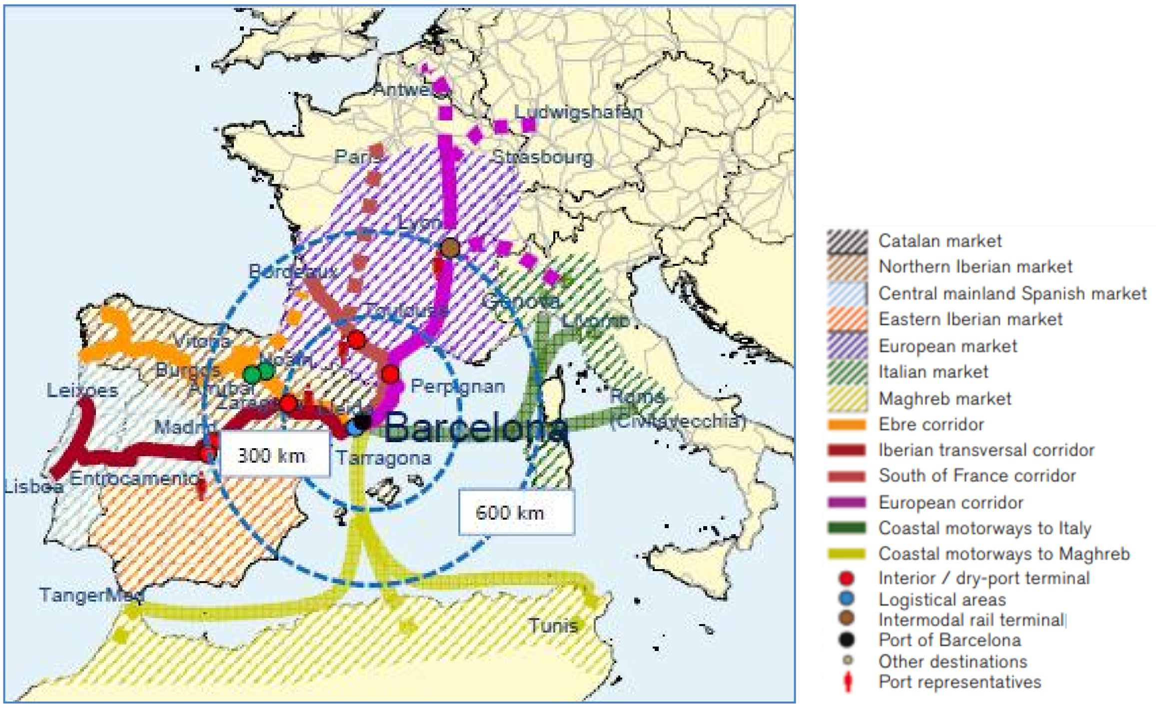

Figure 2-10 Hinterland, rail network [11]

Some data worth remembering:

- Within a radius of 600 km, there are cities such as Zaragoza, Madrid, Valencia, Toulouse, Perpignan and Lyon.
- Less than 24 hours away in terms of distribution (about 1.200 km), cities like Paris, Milan and Lisbon.
- In terms of maritime communications, and located less than 24 hours away, Barcelona is connected to Genova, Rome, Livorno, and Maghreb.

2.2.2. Proximity to a major consumer market

With about 7,5 million inhabitants and a GDP of 234.651 billion Euros (year 2017), Catalonia has one of the largest specific weightings in the Europe of the Regions.

60% of its population is concentrated in an area of 25km around Barcelona, the so-called Metropolitan Area of Barcelona, which is one of the most dynamic areas in Europe.

Besides its local consumption potential, Catalonia and Barcelona's geostrategic location is optimal for distribution to the major consumer markets in southern Europe.

2.2.3. The existence of an important production base

Catalonia has always been the engine driving the Spanish economy with high levels of industrial and business activity. Occupying 6,4% of Spain's land and accounting for 16% of its population, Catalonia has generated 25% of Spain's GDP and accounted for 26% of national exports in 2017.

The existence of a network of infrastructures that is continuously growing promotes the interconnection between different modes of transport and makes up one of the most competitive intermodal logistics systems in Europe. In 2017 this logistics system handled about 400 million tonnes.

Catalonia has a number of major European companies, both in terms of production centres (Seat, Nissan, Celsa, Codorniu, Mango) and also in terms of large multinationals' distribution centres for southern Europe (Amazon, Decathlon, Ikea, Inditex, Carrefour).

2.2.4. A network of logistics platforms

They are directly connected to the country's major infrastructure and intended to serve both the local market and the southern European area.

Changes to trade routes in the last few years have developed Barcelona's position as a Euro-regional distribution hub:

- In the XXI century, the main trading routes changed compared to previous centuries' routes. Until then, the main economic route was the transatlantic one, but now the Asia-Europe route is three times as important compared to the former in terms of container traffic. This has put the Mediterranean at the centre of the main routes between Asia and Europe because is much more efficient and sustainable than via the ports of northern Europe.
  Regarding these routes, using the Port of Barcelona can reduce travel time by 3 or 4 days compared to ports such as Rotterdam and Hamburg, with the consequent reduction in fuel consumption and CO_2 emissions.
- Additionally, we should take into account the fact that trade flows with North

Africa will follow a rising trend and Barcelona will increasingly take on a leadership role regarding these types of traffic.

2.2.5. The Port of Barcelona

The Port of Barcelona is a reference port in the Mediterranean area. The port handles a quarter of all foreign trade out of Spain and three-quarters of foreign trade coming from Catalonia. It is connected to over 850 ports worldwide through established regular shipping lines with its hinterland and through an extensive network of road and rail infrastructure.

The importance of the Port of Barcelona is not only limited to freight, and currently, it is the top cruise port in Europe and the Mediterranean, occupying the 4th position in the world ranking.

At the moment, the Port of Barcelona is undertaking enlargement works that will double its capacity both quantitatively (piers, docks, cranes, access) and qualitatively (new lines, more services and connections).

The Port of Barcelona has worked hard in recent years to expand its area of influence or hinterland. As such, the Port of Barcelona is putting into place local infrastructure located strategically at inland maritime terminals in order to serve new customers in the regions of Aragon and the Ebre Valley, Madrid and the centre of the Iberian Peninsula, southern and central France, and North Africa.

Currently, there are terminals operating in Zaragoza and Toulouse, and another interior terminal is being built in Madrid. These three terminals are connected by rail to the Port of Barcelona. In addition, the Port of Barcelona also operates at the terminals of Azuqueca de Henares (Guadalajara), Coslada (Madrid) and Perpignan, also connected by rail to the Port of Barcelona, and it is developing a new Intermodal Maritime Terminal Centre in Yunquera de Henares (Guadalajara) and another terminal at Vilamalla (Girona).

In line with its hinterland expansion strategy, in 2009 it launched the Barcelyon Express container rail service that connects the Port of Barcelona to Lyon (France) on International Standard gauge track. It's important to note that in 2011, Barcelyon Express traffic rose by 147% compared to the previous year and train container freight rose 41%. Since July 2011, the Port also runs a rail service to Toulouse and Bordeaux. [11]

As seen in Figure 2-3 and 2-5 of the previous section, Barcelona is the only port in Spain to have an International Standard gauge and to be able to handle 750-meter trains.
Projects, studies and works related to Barcelona's logistic area of influence aim to position Barcelona as the centre of distribution in the Mediterranean Euro-region and compete with ports like Rotterdam or Hamburg. By 2020 the Port wants to be handling 70MT of cargo. [11]

In 2018 the Port of Barcelona recorded its best results yet in the main traffic indicators, as total traffic (including all cargo modes) surpassed 67MT for the first time. That is a year-on-year increase of 10,2%. This result contributed significantly to the excellent behaviour of container traffic, one of the most strategic segments of activity for the Port and also a more representative marker of the surrounding economy. In total, 3.422.978 TEUs[4]. were moved in 2018, representing an increase of 15,1% regarding 2017. [12]

China continues to be the Port of Barcelona's prime trading partner, both in terms of imports (44,3% of foreign trade containers unloaded in the Catalan facility come from there), and exports (it receives 11,6% of the containers leaving the port). The remaining trading partners and the type of products transported are highly diverse. [13]

Barcelona's rail Port traffic of containers by corridors in 2016 (Figure 2-11) [14]:

- 72% Iberian corridor (Barcelona - Zaragoza - Madrid)
- 26% Ebre corridor (Barcelona - Pamplona - Burgos)
- 2% International (Lyon)

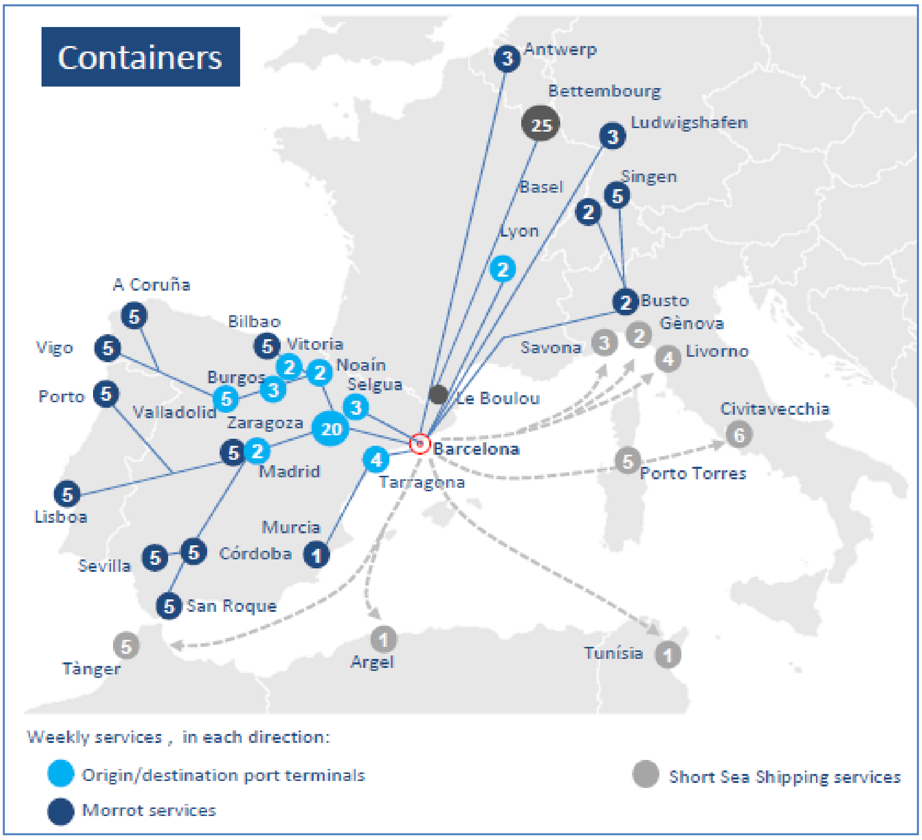

Figure 2-11 Rail Port of Barcelona traffic by corridors

[4] *TEU, Twenty-foot Equivalent Unit is an inexact unit of cargo capacity based on the volume of a intermodal container.*

2.2.6. The Rail Network

The Spanish government has begun a Strategic Plan to promote railway freight transport aimed at making improvements to the Iberian gauge track as it is discontinued.

Amongst the different action programmes, we can highlight a notable increase in the length of trains (450 to 550m) that use the Ebre corridor, with the final objective of reaching train lengths of 750m.

Catalonia has a network of interconnected railway terminals, which extend the railway to the main production and consumption centres in the country.

Various programmes have enabled Barcelona to become the first city in Spain where you can develop UIC gauge railway services to Europe. The action programmes in this process have benefited rail services to Europe, and these are now attracting a lot of interest.

These new services include:

- The Barcelyon Express service, which joins the Port of Barcelona's two container terminals (TCB and Tercat) with the rail terminal at Naviland Cargo terminal in Venissiuex (Lyon). Currently, trains that run between Barcelona and Lyon are now up to 630 meters long (made up by 30 wagons).
- The rail service that connects the Port of Barcelona, Toulouse and Bordeaux has doubled its frequency, offering two weekly departures in both directions.
- It is also worth highlighting that the Barcelona-Switzerland service via Milan has a frequency of two trains per week in both directions, thanks to an agreement with the operator Hupac.
- Recently, a new Hupac service has been added which connects the Barcelona's Port terminal of Morrot with Antwerp, a key logistical hub in the region of northern Europe. This service is provided three times a week with forecasts expecting 4.500 tones to be transported every week.

2.3. NEW TERMINAL SITE ANALYSIS

According to Article 2.2.c of Regulation 913/2010/EU [2], terminals are defined as those facilities provided along the freight corridor which have been specially arranged to allow either the loading and/or the unloading of goods onto/from freight trains, and the integration of rail services with road, maritime, river and air services, and either the forming or modification of the composition of freight trains; and, where necessary, performing border procedures at borders with European third countries.

Terminals are described in the Corridor Information Document [8] by their characteristics, as listed below:

Trains per day: daily average number of scheduled freight trains services in and out of the terminal;

Business model: Public (Infrastructure Manager, Railway Undertaking, Port Authorities, Local or Regional Authorities…) or private ownership, direct management or based on a concession or P3 agreement;

Main functions: Characterization of the terminal and identification of operations developed in the facilities (traffic regulation, relay station, marshalling yard, inland or seaport intermodal, load/unload handling, border/customs, gauge change facilities, etc);

Storage capacity: Total capacity for storage of loading units (TEUs);

Handling capacity: Number of loading units handled yearly (TEUs per year);

Intermodal traffic: Total number of incoming and outgoing TEUs dispatched per year;

Storage utilization: Average storage capacity utilization rate (%);

Handling utilization: Average handling capacity utilization rate (%).

In general, a terminal need being:

- alongside an existing railway line;
- alongside a major highway route;
- just on the bank of sea bay or bank of an inland waterway;
- on flat terrain, level with the railway line;
- near to the origin/destination of freight;
- distant from residential areas;
- next to developable land for expansion.

For intermodal terminals, additional requirements are:

- room to store containers;
- hard standing;
- space for crane/stacker/AGV movements;
- at least 3 running lines together with reception sidings;
- space for road vehicles' movements.

Gathering those listed requirements, the already mentioned necessity to promoting intermodality between rail and other transport modes by integrating terminals into the Corridor, the "last mile" bottleneck in freight rail facilities and the priority to connect the southern area of the Port of Barcelona with the Corridor (as said in the *Third Work Plan of the European Corridor* [15]), made consider the Port of Barcelona as the most strategic point to locate the new terminal. See Figure 2-12.

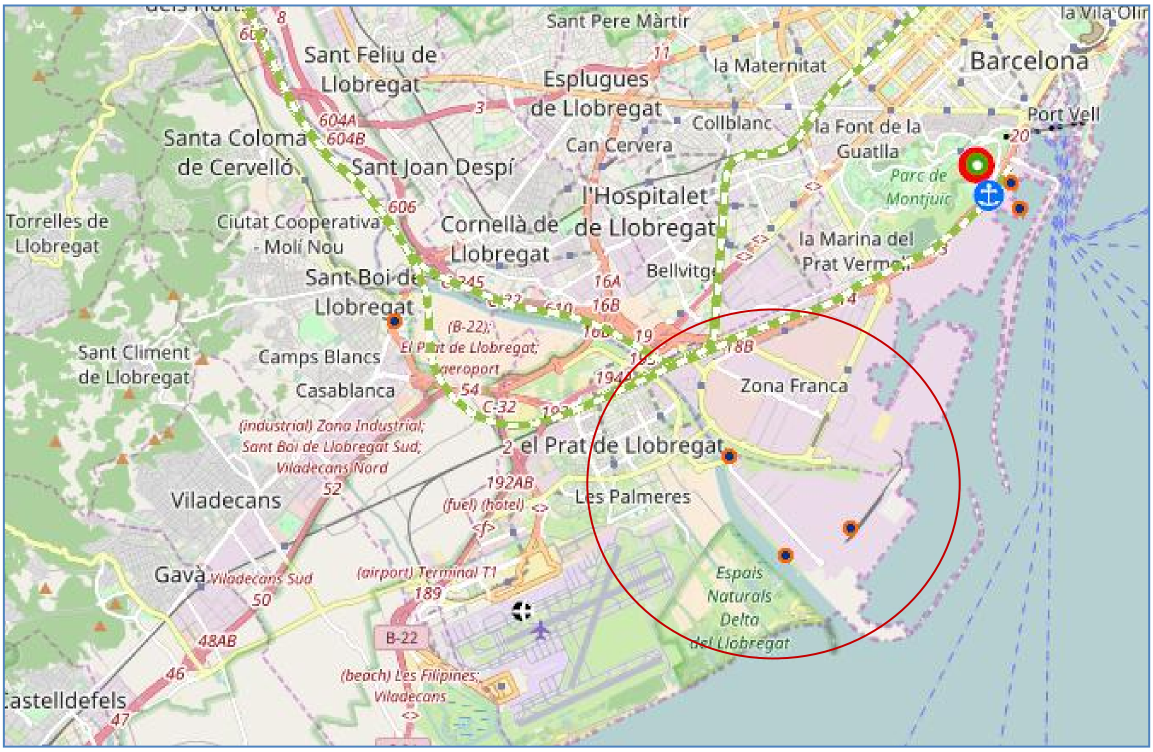

Figure 2-12 Mediterranean Corridor - Southern area of Port of Barcelona. [7]

Moreover, the main stakeholders CEF/TEN-T, *Port de Barcelona* and ADIF, are interested on this new terminal location proposal as they are both investing on specific projects regarding the southern area of the Port of Barcelona.

On one hand, the CEF/TEN-T is co-financing the project titled "New Southern Rail Access to the Port of Barcelona – Phase 2 - Connection Works" as seen in the previous section of the present work. This project involves the construction of the new rail access to the Port of Barcelona to handle all the rail traffic that travels through the new Port expansion area and the logistic zones, where most of the traffic transiting the Llobregat Delta area originates.

This action includes the construction of approximately 11 km of rail access, connecting the new Port expansion area with the "Railway Network of General Interest to the State" (RFIG), as well as joining the infrastructure with the Can Tunis station. 27 km of railway tracks will be needed to build the rail connections, implementing the works defined in the different activities. [16]

The design of the new rail access is planned for the south of the Barcelona Port along with a corridor previously occupied by the course of the Llobregat River before it was diverted in 1999. This corridor will absorb more than 70% of the rail traffic in the Port.

As mentioned in the previous section of the present work, this new railway access is one of the pre-identified projects of the Mediterranean Corridor included in Annex I of Regulation (EU) No. 1315/2013 of the European Parliament and of the Council of December 11, 2013. [8] In the Work Plan of the Mediterranean Corridor [15], this access has been identified as a bottleneck in the Mediterranean Corridor.

The new access to the Port will improve traffic conditions, alleviating traffic congestion in the Metropolitan Area of Barcelona, bringing with it important savings for the economy in terms of fuel, time and a reduction in the number of accidents.

Activities included in the project (Figure 2-13):

1. New rail access section 1. Single rail track.
2. New rail access section 2. Access rail tracks and Marshalling Yard Terminal.
3. New rail access section 3. Connection with the Can Tunis Marshalling Yard.
4. Control and command signalling system.
5. Traction substation.
6. New rail access. Access track and a Marshalling Yard in Ronda del Port.
7. Coordination and management of the project.

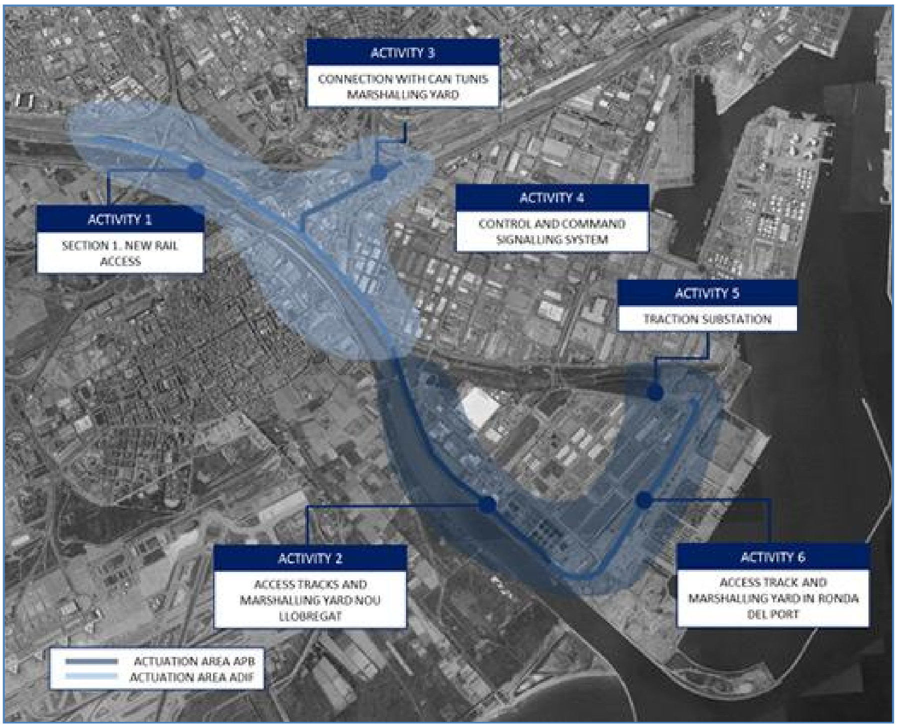

Figure 2-13 Activities of "New Southern Rail Access to the Port of Barcelona" project. [16]

See Attachment II for a complete table with the identifying data of this EU Project.

On the other hand, the other main stakeholder, the *Port de Barcelona,* is currently undertaking strategic expansion works gathered in the so-called "III Strategic Plan of the Port of Barcelona 2015-2020".

After the completion of the dicks in 2008 and the construction of several docks, the port infrastructures of the Port of Barcelona are ready to deal with new traffic. Thus, it is worth mentioning the expansion of the ZAL (Logistic Activities Zone), the construction of the new Best terminal[5] or the extension of the TCB container terminal, the improvement

[5] Hutchison Ports BEST, the first semi-automated terminal in the Hutchison Ports Group and the most technologically advanced port development project in Spain.

of the railway terminals, which can handle 750m compositions in UIC and Iberian widths, the new Grimaldi terminal for short sea shipping and the increase in the capacity of liquids to dojo at the dock of the Energy.

Regarding connectivity, the road actions guarantee high-capacity accesses. Likewise, the "Railway Master Plan" defines the projects that are considered necessary in access infrastructures and in the connections.

Among others, it specifies the construction of a dedicated or preferred line for freight in mixed-width (Iberian and UIC) that connect Barcelona to the French border and create new loading and unloading terminals, and reception and expedition, along with the redevelopment of the entire railway environment of the Port (Morrot, Can Tunis, etc.).

The construction of the new accesses to the Port of Barcelona, whose development has been unblocked in 2013, should allow a +20% container rail freight in 2020. [17]

The last actor in the construction of the new access to the Port is ADIF, which will contribute with €48.660.102 of the €120.431.565 total cost (the other budget for the action is financed by *Port de Barcelona*). The co-financing from EU through the Connecting Europe Facility (CEF) programme will represent 30% of total eligible costs, which equals to €36.129.469.50.

Taking into consideration all the terminal needs, the additional intermodal terminal requirements, the stakeholders' mutual interests, the new rail access planned along the old course of the Llobregat River and the available room in this mentioned area, made choose the old course of Llobregat River as the location site for the new terminal. See Figure 2-14.

Figure 2-14 Location site of the new terminal. [17]

2.3.1. PESTLE Analysis

PESTLE is an abbreviated form for Political, Economic, Social, Technological, Legal and Environmental. The PESTLE technique can make sure that a project is in accordance with the political, economic, social, technological, legal and environmental factors prevailing in the external environment.

In Table 2-1 below, a PESTLE analysis of the new terminal located in the southern part of the Port of Barcelona.

PESTLE analysis	
Political	• The project of the new rail access to the Port of Barcelona has been approved by the Government. The governmental support comes from both the local and national authorities, as it is believed this new facility will help to boost the local and national economy, improve the logistic transportation activity in the ports sector and create new jobs. • Regarding the pass of the Mediterranean Corridor through Catalonia, the Spanish Government continued to plan everything through Madrid despite having the main seaports along the Mediterranean Coast. In order to unblock this political situation between the Spanish government and the Catalan one, the European Union introduced the official notion that the Corridor had two branches: the central (Algeciras-Madrid-Zaragoza-Barcelona), and the coast (Barcelona-Tarragona-Valencia-Murcia), which means that both branches will benefit from EU funds. • Continuous concern about the environment has arisen among governments of developed countries and taxes on fuel have been advocated as a way to reduce carbon emission. Fuel duty is increasing especially on fuels which are intended for transportation and this results in higher costs for delivering goods: it becomes then necessary to promote transport modes non-fuel powered like trains.
Economic	• The project was scheduled for completion in 2016, but the difficult economic situation in recent years caused Spain to slow down on construction. • EU financing investments through the CEF/TEN-T programme for the construction project of the new rail access to the port. • Barcelona, which will have first-class airports, seaports, passenger High-Speed Trains, and international width rail track for freight transportation connecting it with Central Europe non-stop, will be a strategic asset for the entire economy of the European Union and an alternative to the current dependence on North Sea ports. • The proximity of the Port of Barcelona to industrial areas and inland container destinations allow the Port to gain a major competitive advantage against the other "potential site competitors" ready to host the new terminal.

	• The new access to the Port will result in great savings for the economy measured in terms of fuel cost, time and accident rate. • Container traffic, compared with the total seaborne trade, grew faster and represents at the moment the main aspect of global port activities. It is to be considered though that the container shipping industry will be registering a particular growth in the developing countries and, elsewhere, commodities tend to be found and supplied locally. • After the completion of the dicks in 2008 and the construction of several docks, the port infrastructures of the Port of Barcelona are ready to deal with new traffic. Thus, it is worth mentioning the expansion of the ZAL, the construction of the new Best terminal or the extension of the TCB terminal, the improvement of the railway terminals, which can handle 750m compositions in UIC and Iberian widths, the new Grimaldi terminal for short sea shipping and the increase in the capacity of liquids to dojo at the dock of the Energy. • The construction of the new access to the Port of Barcelona should allow a +20% container rail freight traffic in 2020. In addition, the new access will also facilitate the traffic of containers from the BEST terminal. • Various programmes have enabled Barcelona to become the first city in Spain where you can develop UIC gauge railway services to Europe. The action programmes in this process have benefited rail services to Europe, and these are now attracting a lot of interest to the city. • Excellent behaviour of container traffic, one of the most strategic segments of activity for the Port and also a more representative marker of the surrounding economy. In total, 3.422.978 TEUs were moved in 2018, representing an increase of 15,1 per cent regarding 2017.
Social	• The new accesses to the Port will significantly improve traffic conditions and prevent the collapse of the metropolitan area of Barcelona. The objective is to decongest the Ronda Litoral and facilitate direct access to the Port.
Technological	• Since decades, globalization, standardization and the need to reach economies of scale made necessary for the biggest ports to manage efficiently the process of containerisation. Now, thanks to the improvement in Information Technologies, it is time to optimize it. • In order to get not only environmental sustainability, but also social commitment, ports and terminals are expected to guarantee safety for employees in all the operations due to the expansion of new facilities, as the new access, and the implementation of new technology systems.
Legal	• The new rail access is one of the pre-identified projects of the Mediterranean Corridor included in Annex I of Regulation (EU) No. 1315/2013 of the European Parliament and the Council of December 11, 2013. • In September 2013, the Department of Territory and Sustainability and the Ministry of Development signed a protocol for the promotion of rail access.

Environmental	• Fewer trucks in the road. Between Valencia and Barcelona are daily moved between 16,000 and 18,000 trucks, a circumstance that has been considered "unsustainable". • Global warming issues remain the primary concern of any industry. Being able to provide services producing the lowest carbon emissions possible gives a competitive advantage, besides contributing to the preservation of the natural environment.

Table 2-1 PESTLE Analysis of the new terminal location.

2.3.2. SWOT Analysis

The SWOT analysis is a strategic planning technique used to identify strengths, weaknesses, opportunities, and threats related to project planning.

Strengths and weakness are frequently internally-related, while opportunities and threats commonly focus on the external environment.

In the following Table 2-2 the SWOT matrix of the new terminal site inside the context of the Port of Barcelona.

SWOT Analysis	
Strengths	• alongside important railway lines, like the Mediterranean and Ebre Corridors; • International Standard gauge; • to handle 750-metre trains; • close to major highway routes, as A-2, AP-7 and AP-9; • located inside the Port; • on flat terrain, level with the railway line; • near to the origin/destination of freight; • distant from residential areas; • with space for AGV movements; • with space for road vehicles' movements; • technically advanced;
Weaknesses	• not in a developable land for expansion; • not illimitable room to store containers; • just one running lines together with reception sidings; • not easy access to the infrastructure as it is an old river bed;
Opportunities	• planned a new lane construction to increase the capacity of the Ronda Litoral; • planned a motorway construction of 9.2 km that will directly connect the A-2 motorway with the Port of Barcelona; • a steady growth of seaborne trade and of container shipping sector in particular;

	• the Port has a geostrategic location and is a transit route between the Iberian Peninsula, North Africa, Europe and Asia; • Barcelona has a high level of cars export, due to SEAT and Nissan factories; • proximity to major consumers. 60% of Catalonia's population is concentrated in an area of 25km around Barcelona, the so-called Metropolitan Area of Barcelona; • proximity to production centers. Catalonia has a number of major European companies, both in terms of production centers and also in terms of large multinationals' distribution centers for southern Europe. Specifically, the area around the Port; • convenient location. The Port handles a quarter of all foreign trade out of Spain and three-quarters of foreign trade coming from Catalonia; • high connectivity. The Port is connected to over 850 ports worldwide through established regular shipping lines; • the Port is undertaking enlargement works that will double its capacity both quantitatively (piers, docks, cranes, access) and qualitatively (new lines, more services and connections); • the Port is in possession of this currently empty area of the Llobregat river's old bed. Therefore, it is interesting to make it economically profitable; • EU projects. co-financing the new rail access to the Port through CEF/TEN-T programme; • the project for the new rail access to the Port of Barcelona has been approved by both the local and national authorities;
Threats	• expensive site as it is close to Barcelona; • Ronda Litoral, the main road access, is highly congested; • Metropolitan Area of Barcelona is collapsed in a traffic point of view; • Barcelona is isolated in Spain in terms of International Standard gauge and 750m train's length; • the construction of a new rail access to the Port was scheduled for completion in 2016, but the difficult economic situation in recent years caused Spain to slow down on construction; • train traffic congestion in section *Martorell-Castelbisbal* which might penalize availability of time windows.; • Turin-Lyon line bottleneck;

Table 2-2 SWOT Analysis of the new terminal location.

As mentioned before, the operational simulation area is supposed to be located in the western part of the old course of Llobregat river (dark red shape), where the new rail access will be located (red line).

The total dimensions of the area are about 1.4 km long and 180m width (rectangular shape). See Figure 2-15 for reference.

Figure 2-15 Southern area of the Port - New terminal location and new rail access.

The new terminal could start operating once the Ministry of Development, through ADIF, completes the new rail access by the river margin and the rail triangle in the port area. The train's arrival would normally be through the new access from the west side, and eventually going from Can Tunis and 4th street.

2.4. LOHR RAILWAY SYSTEM

The Lohr Railway System or Modalohr System uses special railway wagons of a type known as piggyback wagons, to carry standard road semi-trailers on the European rail network (see Figure 2-16).

Figure 2-16 Lohr, horizontal loading/unloading technology [19]

They are currently used on the AFA (*Autostrada Ferroviaria Alpina*) route; "Alpine" between Chambéry and Turin and the "Lorry-Rail" between Luxembourg and Perpignan; “VIIA Britanica” between Calais and Le Boulou (1.400 km) and the route from Sète to Paris (815 km) and Zeebruge (1.150 km). They have been approved for the Channel Tunnel between the United Kingdom and France and tested from the French border to Can Tunis Barcelona terminal.

This articulated railway wagon (see Figure 2-17) consists of two low-floor decks, resting on:

- A single Y25 jacobs bogie in the middle
- Two Y33 bogies on the extreme ends; a variant of the standard railway wagon bogie Y25. It is been developed for the use in special wagons such as the combined cargo. Compared to Y25 it features an increased wheelbase of 2m. Therefore, the smooth operation at high speed is guaranteed despite its identical bogie design.

Using standard bogies resulted in lower maintenance costs compared with the similar rolling highway concept. The deck between the bogies pivots 30° allowing the trailers to be loaded from the sides.

Lohr wagons are designed to use standard bogies of both UIC and Iberian gauge (see Figure 2-17).

Like their compatibility with both horizontal and vertical loading, this versatility gives the Lohr wagon a better resale value and thus reduces risks for its buyer.

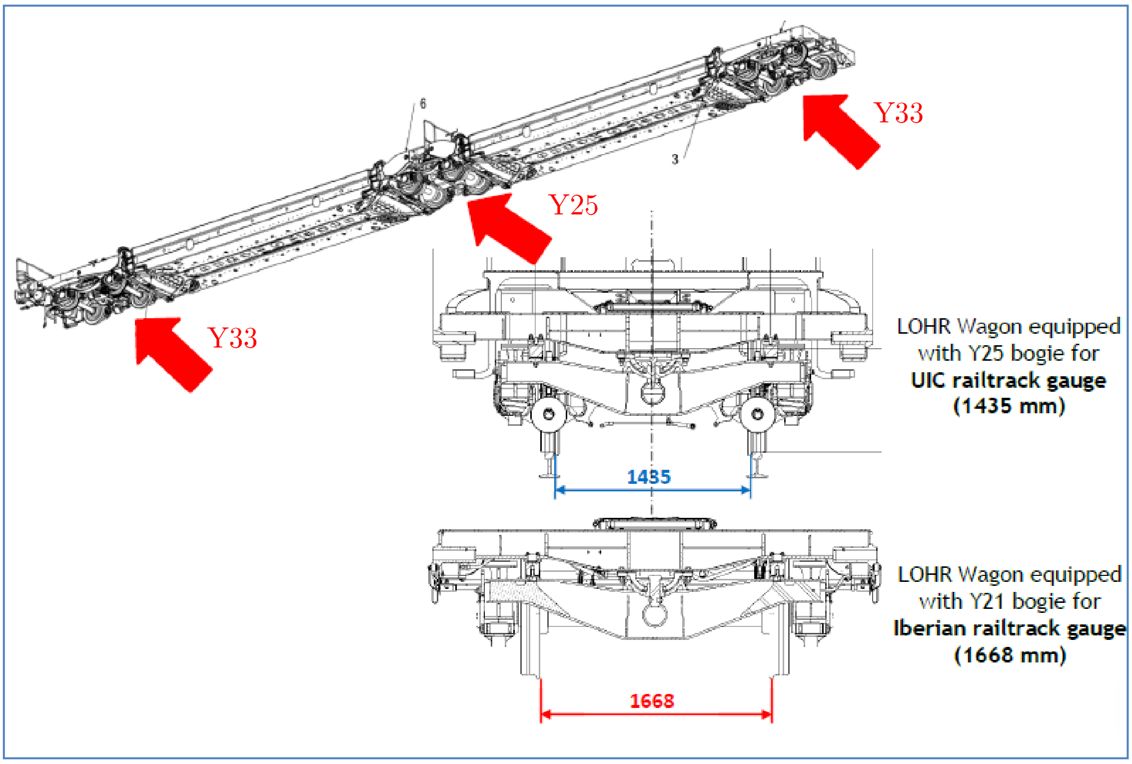

Figure 2-17 Lohr Wagon (Y25 and Y21 bogie) [18]

Thanks to European TEN, Lohr UIC wagons are already tested between Perpignan and the Port of Barcelona (Can Tunis terminal). This test shows that UIC Lohr wagons can be used on the existing rail infrastructure without any additional modification of the rail infrastructure.

The new Loh UIC wagon offers a cradle that pivots 30 degrees so that a standard, 4-metre, non-reinforced semi-trailer can roll aboard on its own wheels. The cranes/AGVs carries the semi-trailer just 22 cm above the rail to keep the trailer within the tight clearances of most European railway lines. This means that the Lohr UIC wagon can transport the 97% of European semi-trailers not reinforced for craning.

Lohr wagons can be used also for the traditional handling at all existing terminals across Europe like the well-known twin pocket wagons, and can also handle the Mega-Trailers that trucking companies have developed to deliver parts for the automobile industry.

This well-established horizontal loading/unloading technology to shift semi-trailers from road to rail system and vice versa provides a solution that is truly competitive, environment-friendly, immediately operational, complementary to road transport, and able to absorb the high levels of transit traffic currently saturating the European road and motorway networks.

It combines the flexibility of the road with the advantages of rail for medium and long distances.

The main specific benefits of Lohr system are:

- **The target market for standard semi-trailers**

  In Europe, most of the semi-trailers are not compatible with conventional combined transport. The Lohr UIC wagon is the only wagon on the French, Spanish and British markets to be able to transport standard 4m semi-trailers and can travel on the main European railway network.

- **A Complement to Combined Transport**

  Compatibility with vertical loading/unloading in existing traditional combined transport terminals.

- **Compatibility with different types of load**

  - Semi-trailers alone (unaccompanied transport)
  - Complete trucks, tractor and semi-trailer (accompanied transport)
  - Intermodal Transport Unit (container, swap body, etc.)

- **Reliability and low maintenance costs**

  - Proven operation in severe weather conditions (heat wave, snow)
  - Proven operation in difficult operating conditions, especially on the Alpine rail motorway. Each train makes 4 to 5 journeys a day on a difficult mountain line (steep gradients, low radius curves and counter-curves)

Development of the Lohr System network in operation and in the short-medium term (see Figure 2-18):

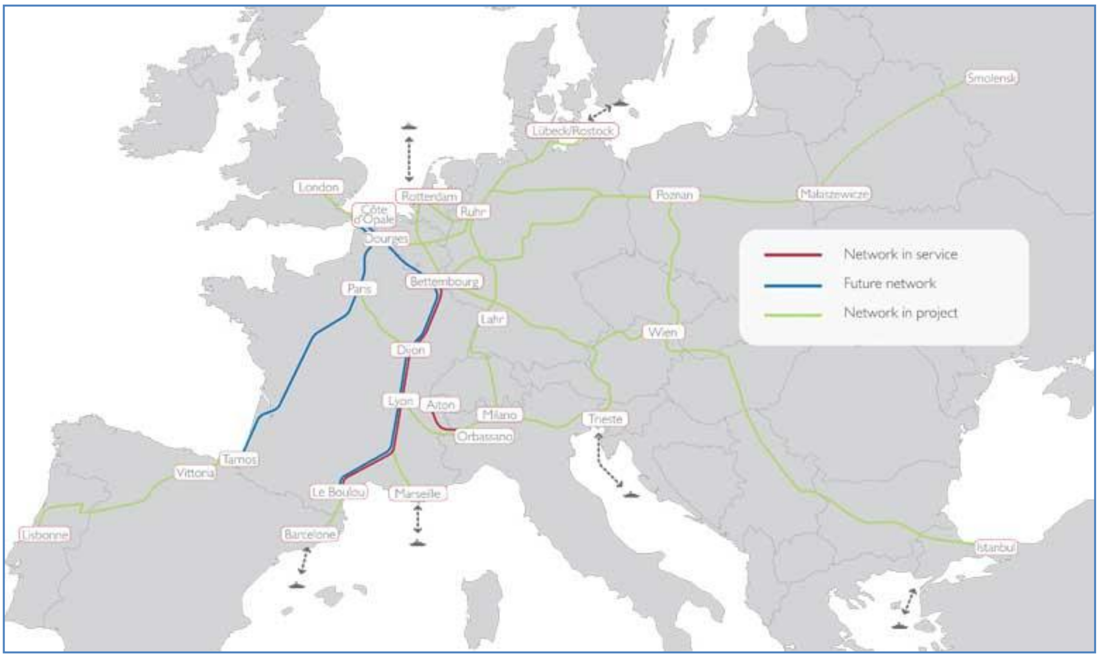

Figure 2-18 LOHR System European network [19]

2.5. NEW TERMINAL DESCRIPTION

The terminal analysed in the present work is a medium-sized terminal (similar to the one in Le Boulou, Figure 2-19) that enables the pockets of Lohr wagons of half a train to be opened simultaneously.

After dealing with the first half, where the U/L operations will be done, the train is moved about 300 meters to deal with the second half.

This type of terminal offers a good investment cost/performance ratio and good processing capacity compared to a complete terminal in which the entire train can be operated simultaneously.

Figure 2-19 Le Boulou (France), medium-size terminal example - aerial

Unloading and then loading of a complete train of Lohr wagons can be performed in about 3 hours on such a terminal. The train arrivals are defined in a train timetable, while the patterns of truck arrivals for ST delivery and pick-up can be either statistically modelled or given as a deterministic input.

The new terminal consists of:

- Port railway network
- Parking spaces
- Unloading and Loading track
- Waiting track
- Road network

2.5.1. Port railway network

Through the railway network trains access and leave the terminal (seen in Figure 2-15).

Details of the railway operations and characteristics are:

- Length of trains 750m;
- International Standard Gauge 1.435mm;
- Manoeuvring locomotives always work by dragging the load;
- The maximum speed of movement in the port is 20 km/h;
- Train circulation is from Monday to Saturday keeping the same schedule for every day. Sunday there is no circulation.

2.5.2. Parking spaces

The parking spaces are not going to be simulated in the present work. However, the choice of parking space would be made with the following criteria:

- The parking space is selected to be as close as possible in time to the loading point in order to reduce the cycle time of the AGVs. This parking position is assigned in the control of the entrance.
- The position in the parking space for the train unloading is selected as close as possible in time to reduce the cycle time of the AGVs as much as possible.
- The length of the STs without a tractor is 13.6 meters and the length with the tractor is 16.5 meters. It is considered that the parking spaces have the necessary dimensions to house the ST with the tractor.

2.5.3. Unloading and Loading track

There is one U/L track composed by of 22 U/L stations. Each station (see Figure 2-20) is accompanied by 4 manoeuvring D/C (disposal and collection) stations. These seats can be considered partially parking as the STs occupy these positions waiting for the load of the train or once unloaded.

Figure 2-20Loading and Unloading station. [19]

The train with a capacity of 44 STs (22 wagons) will be operated in 2 stages. In the first, U/L of the first half of the train 22STs (11 wagons), and, in the second, the other half, moving the train along the rail track to position it in the station area.

Figure 2-21 shows the 4 parking D/C stations associated with each U/L station. The squares 1 and 2 are associated with the unloading (1) and subsequent loading (2) of a position of the first segment of the train, and squares 3 and 4 are associated with the unloading (3) and subsequent loading (4) of a position of the second segment of the train.

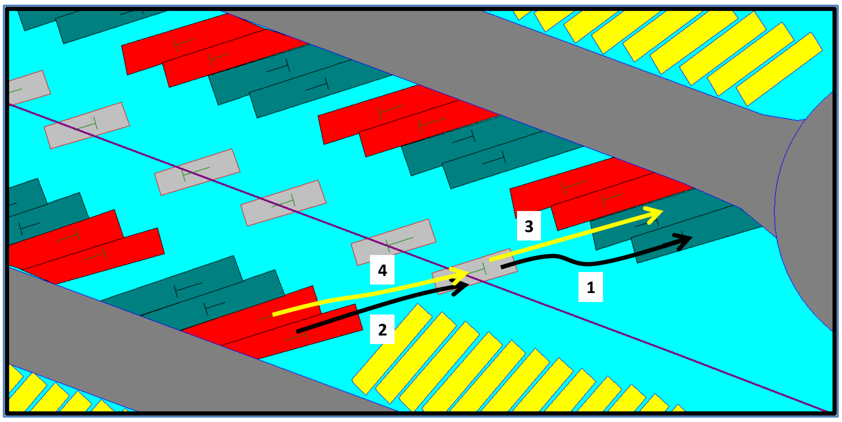

Figure 2-21 Detail of the process of unloading/loading the train.

Observing the operative of D/C in *https://www.youtube.com/watch?v=MTvSOrTXFzw&t=* it is emphasized that all stations in each two train segments are downloaded first, and then, all positions are loaded. In the simulator, this same procedure will be followed.

The dynamics of the process is:

1. AGVs move STs to be loaded from the parking spaces to the boarding C/D places. (not simulated)
2. AGVs download the STs of the first segment of the train.
3. AGVs load the STs of the first segment of the train.
4. Movement of the train. Take advantage of the 'dead' time between the first segment and the second segment to move downloaded STs from the collect spaces to the parking spaces (not simulated).
5. AGVs download the STs of the second segment of the train.
6. AGVs load the STs of the second segment of the train.
7. Use the time between the departure of one train and the arrival of the next to move all the STs downloaded to the parking spaces (not simulated).

2.5.4. Waiting track

6 waiting tracks, four of them owned by the new terminal and the other two located in the Zal Prat terminal. The locomotive moves the train from waiting tracks to U/L track.

2.5.5. Road network

The road network allows the movement of the AGVs with or without the STs, and the movement of the trucks. The road network includes an access control gate in the west entrance and one exit at the east end of the terminal (control gate not simulated).

2.6. SIMULATION ASSUMPTIONS

In the next section, the modelling assumptions to simulate the terminal are described. Further explanations are held in the next sections of the present work.

Discussions of the layout and the port railway network have been held with Antoni Guasch, the UPC thesis director. This layout proposes a central U/L track with Lohr equipment for 22 U/L stations (11 wagons).

Each U/L station contains 2 delivery and 2 collection (D/C) stations for each wagon. Therefore, the D/C places are 4 x 22 (88 stations), dedicated to giving room for the STs during the loading and unloading operations of the train (see Figure 2-22).

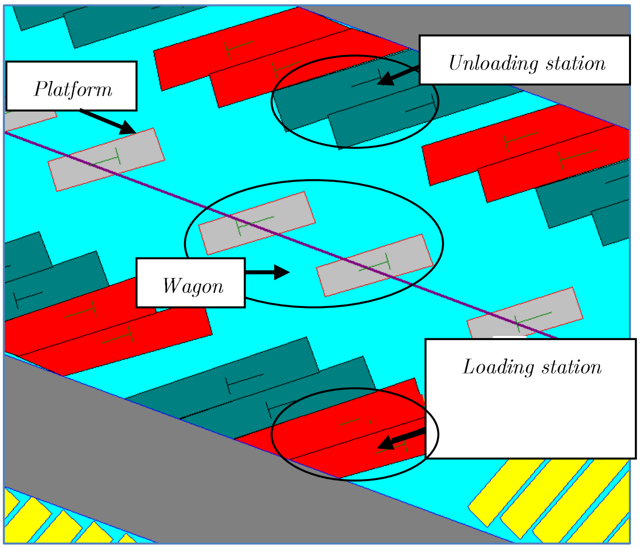

Figure 2-22 U/L track. Elements: wagon, platform, U/L station and D/C station.

On the other hand, the set of assumptions adopted for the study:

1. It will be assumed that the arrival of trains will be distributed evenly between 24 hours a day. For 5 trains/day we will have a train arrival every 24/5 = 4,8 hours and for 8 trains/day we will have a train arrival every 3 hours. Those arrivals will be constant and regular. Trains arrival/departure timetable is not influenced by the rail network availability, which means that availability is always assumed.

2. The U/L of the wagons is always done in two stages. Firstly, for the unload, the ST is moved to the Collection station and after from the Collection station to the parking space. The opposite for the load. The parking space dynamics will not be simulated.

4. The U/L operations of the STs from/to the D/C stations by the AGVs have no interference with the movement of the trucks.

5. The U/L dynamic of the STs from/to the D/C positions is simplified in the simulation model. The dynamics of the trucks in this area will not be modelled and the arrival of the trucks will follow a timetable.

6. All AGVs work in teams simultaneously in the same type of operations. Therefore, we will not find, for example, a subset of AGVs unloading the train and simultaneously another subset loading it. This hypothesis ensures orderly management of operations.

7. There is no direct delivery of the STs to the train or direct collection from the wagons. The STs are always U/L from the make the delivery/collection stations.

8. It is assumed that the AGV's coupling or unhooking operations do not interfere with the general circulation through the roads.

9. The simulation of the route of the trains through the port will be made without taking into account the rest of the traffic.

10. During the simulation, various design parameters are set to assess the performance of the terminal resources. The data have been found on different sources and have been discussed with the thesis director, Antoni Guasch.

2.7. SIMULATION BACKGROUND, STATE OF ART

Rail intermodal terminals differentiate from maritime intermodal terminals since they are “inland” and they are nodes in a tightly interconnected network, composed of the rail and the road networks.

They are usually smaller than their maritime counterparts and the residence time of ITUs (Intermodal Terminal Units) in the terminal is usually much shorter. In such terminals, particular care must be devoted to the model of the arrival and departure processes of trains and trucks at the terminal gate. [20]

A consistent number of researchers have worked on the problem of the simulation and the optimisation of the rail network, Cordeau, Toth and Vigo (1998), and a comparable effort has been put into the research on traffic simulation, Pursula (1999). These studies are of great importance since their results can be used to model the “interfaces” of the terminal with the external world.

Another simulation tool dedicated to model a single terminal was introduced by Benna and Gronalt (2008). Terminal layout, arrival patterns of trains and trucks, and container settings were specified as part of the input data. [21]

A general overview of the macro and micro model was provided by Ballis and Golias

(2002). They identified main design parameters for railroad freight transport terminal. The proposed length of transhipment tracks, the number of handling equipment and stacking height in the storage area as design parameters.

Alicke (2002) modelled the transhipment operation in an intermodal terminal by using an optimization model based on constraint satisfaction. [20]

Corry and Kozan (2006) addressed the load planning problem in intermodal rail terminals.

In the field of container terminals, many studies have been done about design problems. Steenken et al. (2004) provided an excellent literature review on container terminal operations and references containing the various optimization methods that have been used to solve logistical problems.

Rizzoli et al. (2002) built a simulation model of the flow of ITUs among and within inland intermodal terminals using MODSIMIII as a development tool. [21]

Marinov and Viegas (2009) provided a yard simulation modelling methodology for analyzing and evaluating flat-shunted yard operations using SIMUL8.

In the last decade, there is a trend of construction of intermodal terminals in port areas. Many advanced container ports plan to expand the port area so that new conceptual rail terminals are constructed in the port area. Thus, efficient rail terminal operations and the optimized rail terminal design became important issues.

In France, in 2007, has been developed a dedicated piggyback system leading to the rollout of the first major "rolling road" for conveying heavy goods vehicles (HGVs) by rail, over a distance more than 1,000 km in length, from the Luxembourg frontier to the Spanish border.

The cornerstone of the system is the Modalohr wagon (or Lohr system, already described in the present work) designed for the sideways loading of road-haulage units, and already in use on the Alpine and Perpignan-Bettembourg "rolling roads". [22]

Lohr system keeps expanding among the European territory, and now could be the moment to arrive to the Catalan capital through the Port of Barcelona. As it is not a standard system, there are not public background simulations or studies in this field.

2.8. SIMULATION SCENARIOS

The simulation model has been structured into three large sub-models:

1. Sub-model of STs flow management
2. Sub-model of the management of AGVs and trucks
3. Sub-model of railway management

For the set of subsystems, the experimentation of 2 scenarios will be contemplated according to the circulation of 5 or 8 daily trains.

2.8.1. Sub-model of STs flow management

Trucks arrive at the terminal to deliver ST, which are then loaded on departing trains, and to pick up STs, which have arrived by train.

In the first case, trucks usually arrive before the train leaves, while in the second case trucks usually arrive after the train arrival, so that they can minimize the length of stay in the terminal.

This sub-model models the arrival rhythms of STs according to the time of the day, providing batches of 22 STs for the first segment of the train and 22 STs for the second segment. Those batches are directly located in the Delivery stations.

It allows a constant flux of STs to be loaded to the train. Therefore the train will never be delayed waiting for delayed STs to arrive.

When the train is loaded with the STs currently present in the Delivery stations will leave the terminal. Therefore, if a truck delivers the ST late, it will wait for the next train window. The closing time for the delivery of the STs for the load is 2 hours before the departure of the train.

Regarding the collection of the STs, it has been simulated that all STs unload, and so moved to the Collection stations, are picked up by a truck before the next train arrival. In this situation, a train will never remain blocked because there is no space on the Collection stations.

The sub-model of STs flow management also models the rhythms of train arrivals in the scenario of 5 or 8 trains a day. This sub-model generates the arrival flows for the rest of the sub-models.

2.8.1.1. Specification of STs arrivals

The terminal is open every day of the week (24/7). However, the carriers do not usually work on Sunday, so there is an inhomogeneous distribution of arrivals and departures of trucks to the terminal on different days of the week.

2.8.1.2. Trains timetable

The arrivals of trains are generated according to a fixed timetable input. The following Table 2-3 and 2-4 show the train schedules for the configuration of 5 and 8 rotations per day (rotation = arrival and departure).

For each table, the STs to be delivered and collected for each day are shown according to the previous specification.

- **5 rotations**: 5 trains/day x 44 STs/train = 220 STs/day
- **8 rotations**: 8 trains/day x 44 STs/train = 352 STs/day

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total week
Hour of arrival train 1	1	1	1	1	1	1	
Hour of arrival train 2	5	5	5	5	5	5	
Hour of arrival train 3	10	10	10	10	10	10	
Hour of arrival train 4	15	15	15	15	15	15	
Hour of arrival train 5	20	20	20	20	20	20	
STs regular flux	**220**	**220**	**220**	**220**	**220**	**220**	**1320**
STs deliveries	220	220	220	220	220	220	1320
STs collections	220	220	220	220	220	220	1320

Table 2-3 Train schedule and ST D/C summary for 5 trains/day.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total week
Hour of arrival train 1	1	1	1	1	1	1	
Hour of arrival train 2	4	4	4	4	4	4	
Hour of arrival train 3	7	7	7	7	7	7	
Hour of arrival train 4	10	10	10	10	10	10	
Hour of arrival train 5	13	13	13	13	13	13	
Hour of arrival train 6	16	16	16	16	16	16	
Hour of arrival train 7	19	19	19	19	19	19	
Hour of arrival train 8	22	22	22	22	22	22	
STs regular flux	**352**	**352**	**352**	**352**	**352**	**352**	**2112**
STs deliveries	352	352	352	352	352	235	2112
STs collections	352	352	352	352	352	352	2112

Table 2-4 Train schedule and ST D/C summary for 8 trains/day.

2.8.1.3. AGVs work phases

The different phases of work and the associated time take as reference the Table 2-5 [19]:

Operations	Conservative time [min]	Margin [min]
Try the brakes	10	0
Realigning the train	5	3
The opening of hulls	5	0
Connection to air system	10	0
Unloading	6	4
Loading	6	4
RAT[6] + Try the brakes	30	0
Translation	5	0

Table 2-5 Operation times for a train segment.

and are,

Phase	Phase description	Time	Needed Operations	Other operations (if free time)
0-1	Time between departure start previous train and arrival 1st current train segment	Minimum time of 30 + 5 + 10 + unif (2,5) + 5 + 10 => 63.5 min average	CP1(i-1) PD1(i)	CP2(i-1) PD2(i)
2	Unload the 1st train segment	(22*tria(2,4,6)) / #AGVs	TC1(i)	
3	Load the 1st train segment	(22*tria(2,4,6)) / #AGVs	DT1(i)	
4-5	Train movement	30 + 5 + 10 + unif (2,5) + 5 + 10 => 63.5 min average	CP2(i-1) PD2(i)	CP1(i) PD2(i+1)
6	Unload the 2nd train segment	(22*tria(2,4,6)) / #AGVs	TC2(i)	
7	Load the 2nd train segment	(22*tria(2,4,6)) / #AGVs	DT2(i)	

Table 2-6 AGVs working phases

[6] *RAT, Recognition of Appropiateness for Transport*

Where,

- the train *i* is the current one, the *i-1* the previous one and the *i + 1* the next one.
- CP: from Collection place to Parking space
- PD: from Parking space to Delivery place
- TC: from Train to the Collection place
- DT: from Delivery place to Train

Tria(2,4,6) is the time of U/L of an ST of the train. It is a triangular probability density distribution of a lower limit of 2 minutes, upper limit of 6 minutes and mode of 4 minutes.

It is interesting to note that in phases 0 and 4 all movements must be made from the D/C places to the Parking spaces (movements CP and PD). If the available time is insufficient, the number of AGVs will have to be increased if the number of trains/day is to be maintained.

The following Table 2-7 shows, for different available AGVs values, the time required for each phase of the cycle and the number of daily trains that can be used as a maximum. Additionally, the total time available for phase 0 is also calculated in which, apart from the minimum time for the departure of the previous train and the arrival of the new train, the additional time available is included.

Phase	Time [min]	3AGVs	4AGVs	5AGVs	6AGVs	7AGVs	8AGVs
0-1	Minimum time of 30 + 5 + 10 + unif (2,5) + 5 + 10 => 63.5 min average	63.5	63.5	63.5	63.5	63.5	63.5
2	(22*tria(2,4,6)) / #AGVs	29	22	17.6	14.6	12.6	11
3	(22*tria(2,4,6)) / #AGVs	29	22	17.6	14.6	12.6	11
4-5	30 + 5 + 10 + unif (2,5) + 5 + 10 => 63.5 min average	63.5	63.5	63.5	63.5	63.5	63.5
6	(22*tria(2,4,6)) / #AGVs	29	22	17.6	14.6	12.6	11
7	(22*tria(2,4,6)) / #AGVs	29	22	17.6	14.6	12.6	11
	Minimum cycle time [min]	**243**	**215**	**197.4**	**185.4**	**177.4**	**171**
	Minum cycle time [h]	**4.05**	**3.58**	**3.29**	**3.09**	**2.96**	**2.85**
	Knowing that the terminal is opened 24/7: 24h / Minimum cycle time [h]	**5.93**	**6.70**	**7.29**	**7.77**	**8.12**	**8.42**
	Max. number of trains per day	**5**	**6**	**7**	**7**	**8**	**8**
	Sum of cycle times depending on the # of trains [min]	1215	1290	1381.8	1297.8	1419.2	1368
	Knowing that the terminal is opened 24/7: 24h * 60 = 1440min/day	1440	1440	1440	1440	1440	1440
	Total extra free time per day [min]	**225**	**150**	**58.2**	**142.2**	**20.8**	**72**
0	**Extra free time phase 0 per train [min]**	**43**	**25**	**8**	**20**	**2**	**9**
0	Total time phase 0 per train [min]	107	88	71	83	66	72

Table 2-7 Theoretical maxim number of trains/day regarding the number of AGVs.

Therefore, for the simulated of 5 and 8 rotations per day, the theoretical possibilities are:

- 5 rotations: 3AGVs with extra time in phase 0 of 43min
- 8 rotations: 7AGVs with extra time in phase 0 of 2min
  8AGVs with extra time in phase 0 of 9min

2.8.2. Sub-model of the management of AGVs and trucks

The objective of this sub-model is to analyze the use of AGVs.

2.8.2.1. Dynamics of the AGVs in the terminal

The general parameters for AGVs are (Le Boulou):

- Movement speed in the terminal: 20 km/h.
- All manoeuvres a reduced speed of 5 km/h.
- Hook-up time: 2 min
- Detach time: 1 min
- Reverse parking time: 2 min.

From the observation of the video *https://www.youtube.com/watch?v=MTvSOrTXFzw&t*, an approximate time of 2 min has been determined for the hooking-up and 1 min for the detach.

The two main scenarios will be simulated 5 trains a day and 8 trains a day. Experimentation will be performed in these two main scenarios to evaluate the sensitivity of the following parameters train cycle time according to the number of AGVs.

2.8.2.2. Dynamics of the Delivery and Collection operations

In regards to the D/C operations we have the following information:

- In the same *youtube video* shown above is observed that a D/C a set of 16 STs (8 wagons) is U/L in 36 minutes with 3 AGVs.

  For each unloading and loading operation, the cycle time per AGV is, therefore,

$$\frac{36\ min}{16\ STs\ \cdot\ 2\ operations} \cdot 3\ AGVs = 3.37\ min$$

- In [19] we find the operating times for an entire train segment (see Table 2-8),

Operations	Conservative time [min]	Margin [min]
Try the brakes	10	0
Realigning the train	5	3
The opening of hulls	5	0
Connection to air system	10	0
Unloading	6	4
Loading	6	4
RAT[7] + Try the brakes	30	0
Translation	5	0

Table 2-8 Operations time for each train segment [19]

The translation time of 5 minutes corresponds to the travel time to move the second half of the train to the U/L zone.

Conservative values minus the 'margin' generate optimistic values. All these operations are carried out on the waiting track and are for each segment of the train, except U/L hulls and Translation.

Therefore, the average time of operation of a train will be:

$$\sum Operations\ time \cdot 2\ segments + Translation\ time + (U\ time + L\ time) \cdot \frac{44\ platforms}{\#AGVs} \quad (1)$$

$$\boldsymbol{Average\ time\ of\ operation\ of\ a\ train_{conservative} = 120min + 5min + \frac{528min}{\#AGVs}} \quad (2)$$

$$\boldsymbol{Average\ time\ of\ operation\ of\ a\ train_{optimistic} = 114min + 5min + \frac{176min}{\#AGVs}} \quad (3)$$

Given that the optimistic and conservative times of D/C are of 2 and 6 minutes, it is proposed to work with a triangular probability density distribution of values 2, 4 and 6 minutes where the most probable value will be 4 minutes, slightly higher than the average of 3.37 min observed in the video.

It seems reasonable to work with the average of 4 minutes given that the average of 3.37 minutes has been obtained with the D/C of a single train with 16 STs with 50% of the D/C parking spaces empty.

It is expected that the times are greater if the operational work contains two train segments when all the delivery parking spaces are occupied before the arrival of the first segment, thus hindering the manoeuvrability of the AGVs.

7 RAT, Recognition of Appropiateness for Transport

2.8.3. Sub-model of railway management

Intermodal transport involves transporting STs on a fully interconnected network, but intermodal corridors are commonplace. A corridor is a privileged point-to-point railway connection between two terminals. The rail corridors made possible for intermodal transport to compete with road-only transport not only in terms of cost but also in terms of time.

A corridor is an abstract representation of a path in a complex rail network. The simulation of a corridor link is driven by a timetable, which contains the departure and arrival times of trains. When a train travels from an origin terminal to a destination along a corridor, the simulator makes the train arrive in the destination terminal after a set time, given by the arrival time minus the departure time, plus a stochastically generated delay, to account for unexpected events.

A train travelling in a corridor must be loaded in the source terminal and unloaded in the destination terminal. In the source terminal, it is represented as a list of STs' bookings. Booking is placed by forwarding companies, which will send trucks to deliver STs according to the booking details (the hour of train departure, type of ST, weight allowance, etc.).

When the train is loaded and its departure time has arrived, it leaves the source terminal for its destination on the corridor. At the destination, the train is unloaded and trucks arrive to pick up the transported STs.

The site scenario contemplated, as mentioned before, depends on the Spanish Ministry of Development action to complete the new rail access by the river margin, and the rail triangle in the port area.

2.9. DIAGRAMS

In the next section is described, using different types of diagrams, how the terminal model can be embedded in the simulation.

2.9.1. Simulation Process

The overall simulation process is given in Figure 2-23. First, the target rail transport requirements must be determined. Second, the design parameters must be estimated based on rail transport requirements. Third, the layout plans for the rail terminal facilities must be constructed based on estimated design parameters. Fourth, a simulation model must be constructed considering the terminal layout and design parameters.

This simulation model is tested by using various scenarios which may consider various design issues and operational issues. After the simulation study, the tested scenarios are analyzed and evaluated.

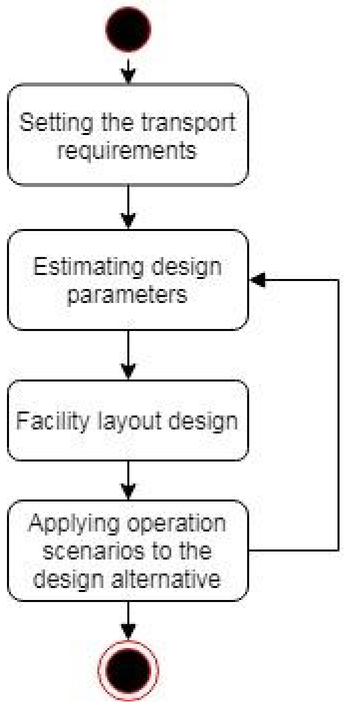

Figure 2-23 Simulation Process

2.9.2. Simulation Sequence Diagram

Figure 2-24 show the entire process of the simulation model.

In this section, we describe what happens to the trains and trucks when they enter the terminal model. In an intermodal terminal it is interesting to examine the processes with reference to the modal change, that is, ST arriving by truck and departing by train, and vice versa. For this reason, we present the terminal processes following their input and output paths.

ST arrival by truck and departure by train

When the truck enters the terminal one of these three cases is given:

a. the ST arrives well ahead of the deadline (the time when the train on which it was booked must leave);
b. the ST arrives just before the deadline;
c. the ST arrives after the train has left.

In the first and second cases, the train might have not left yet. In both situations, the truck is directed to the Delivery spaces to leave the ST that will be loaded to the train by the AGV.

If the ST arrives after the train has left, the truck joins the queue at the storage area (not simulated) which contains the STs that missed their train and that have to be rebooked on another train.

Trains depart from the terminal according to a fixed timetable. This constraint is never violated in the simulation model and therefore it might happen that some trains depart before all the booked STs have been loaded. Such an event is used as an indicator of a malfunction in the terminal processes.

STs arrival by train and departure by truck

When the train arrives at the destination terminal, it is directed to the waiting track where it waits for the availability of the rail track (it might be engaged by another train). When this precondition is satisfied, the train may enter the terminal and the unloading operations start.

In the meantime, trucks are arriving to pick-up the STs delivered by the train. Truck arrivals for ST pick-up are symmetric to arrivals for delivery, in the sense that trucks arrive generally after the train has arrived and the highest number of STs is picked up a few hours after train arrival.

When an empty truck arrives at the terminal four alternatives are given:

a. the requested ST is stored in the storage/buffer area (not simulated);
b. the ST has already been unloaded from the train and it is stored in the Collection space;
c. the ST is still on the train, waiting to be unloaded;
d. the truck has arrived before the train.

In the first case, the truck is directed to the storage area. In the second and third cases, the truck is directed to the Collection space. Finally, if the requested ST is not in the terminal, the truck waits for its arrival in a dedicated queue (not simulated).

As said in previous sections of the present work, it is assumed a time window, from Monday to Saturday, which trains are allowed to run. The carriers do not usually work on Sunday, and trains are neither arriving on Sunday. In case trains which arrived after the end of the time window must wait until the beginning the time window of the next day.

The following diagram is an example to describes the sequence of two trains. For the first one is assumed that all Delivery spaces are full of STs and that all Collection spaces are empty. Also for the first train, the trucks arriving at the terminal do not bring STs, are just collecting the ones of the train. For the second train, the trucks arrive at the terminal with STs and leave with or without ST.

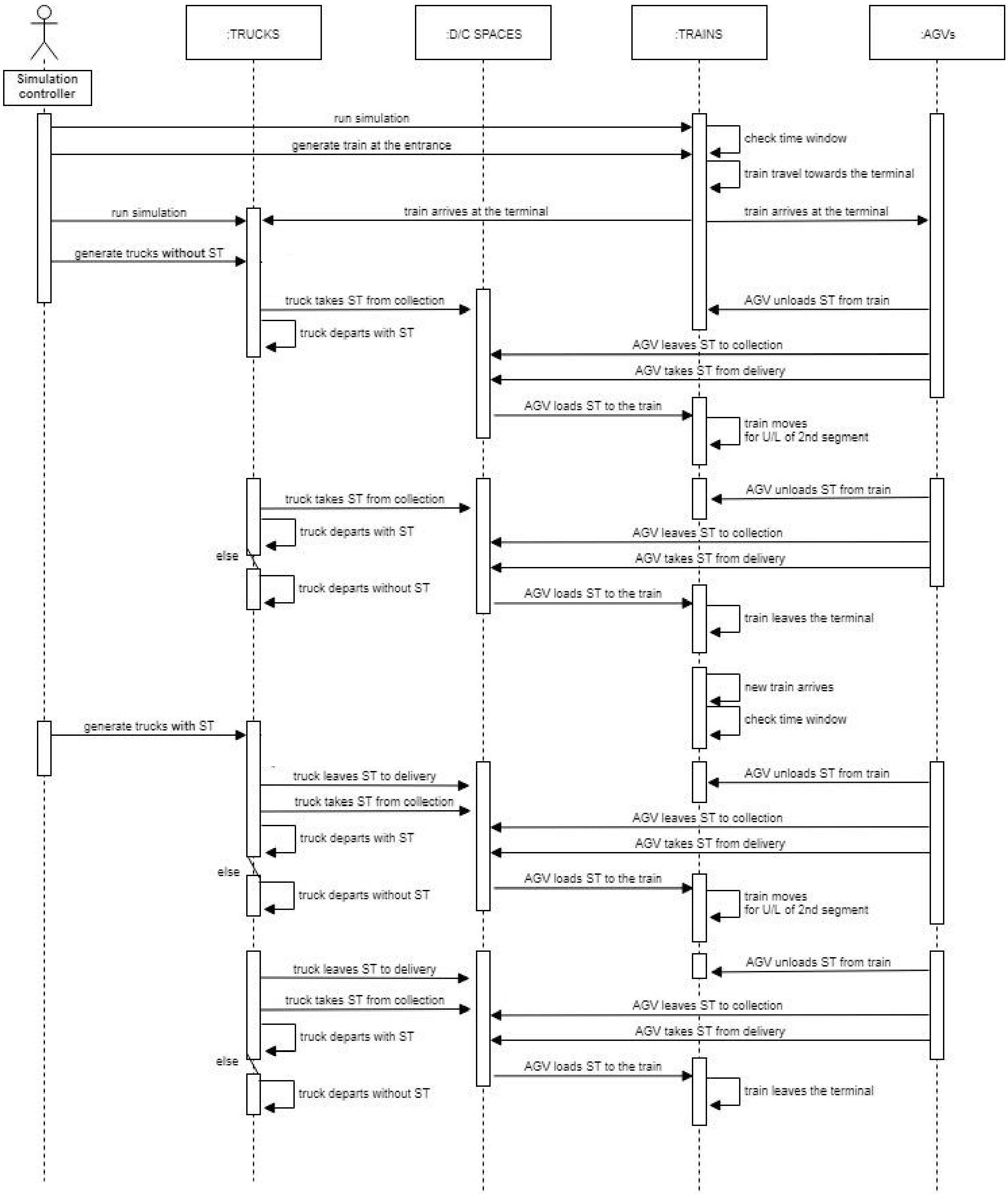

Figure 2-24 Simulation Sequence Diagram

2.9.3. Operation Diagrams

In the following section of the present work are found the train, trucks and AGVs diagrams.

2.9.3.1. Train Operation

The train operation diagram is shown as Figure 2-25 explains the different operations faced by each train during the simulation process, from checking the time window and arriving at the terminal until leaving the terminal.

Trains are modelled as sets of STs to be moved. Each move is an operation and a sequence of operations is a job. Thus, a sequence of loading/unloading operations for a train corresponds to a job. Each operation has a priority (for instance, if the ST is to be picked up by a truck). Each operation is assigned to the available AGVs, ordering by priority.

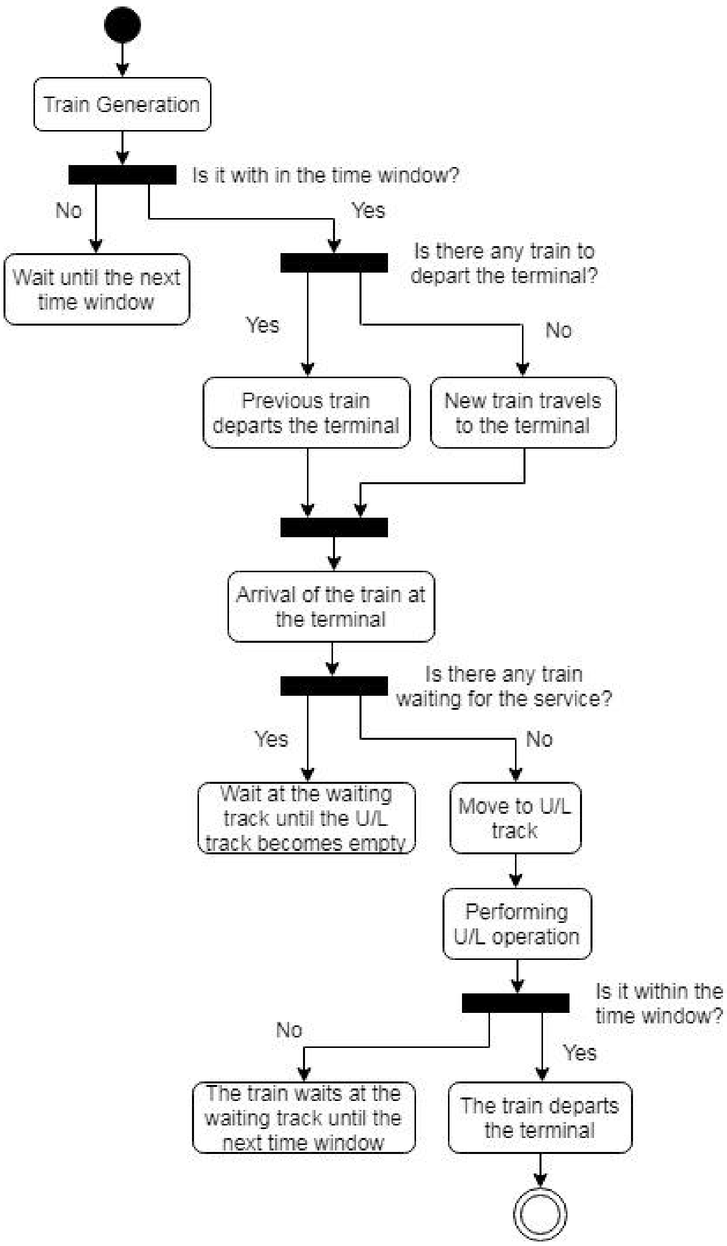

Figure 2-25 Train operation

2.9.3.2. Trucks operation

Figure X shows the operation process of trucks. Depending on the attributes of that truck, with or without STs, not simulated, the truck will:

- Collects an ST and leave the terminal

- Deliver an ST and leave the terminal
- Deliver an ST, collect and ST and leave the terminal

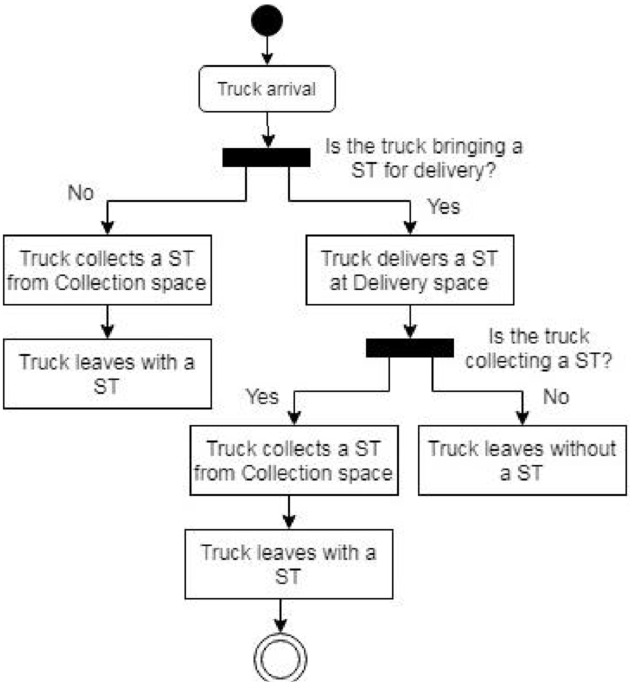

Figure 2-26 Trucks operation

2.9.3.3. AGVs operation

Next, the operation of an AGVs was analyzed. Figure 2-27 shows the operation process of the AGVs. AGVs are assumed to perform U/L operation tasks in the increasing order of the travel distance from the current position of the AGV to the position of each task. If there is no task to perform, then the AGV stays still a new task arrives.

The possible operations performed by an AGV are:

a. loading an ST on a wagon of a departing train from the Delivery space;
b. unloading an ST from a wagon to the Collection space;
c. bringing an ST from the Collection space to the storage/buffer area in the case the truck arrives late to pick it up (not simulated);
d. bringing an ST from the storage area to the Delivery space in case the truck arrives late to leave the ST and it has to be stored in the storage/buffer area for the next train (not simulated).

The order of the operations when loading a train is the following: first the STs on the Delivery Spaces. Secondly, and if the train is not full, the AGV takes the STs stored in the storage/buffer area and placed directly in the train (not simulated).

When unloading a train the order is: first move the STs on the Collection spaces. If the truck is late to pick up the ST from the Collection space, and the next train arrives, STs are moved to the storage area by the AGVs (not simulated).

The list of the AGVs that will be active during a given work shift is set by the simulation controller.

The operations performed by AGVs depends on the following factors:

- Presence or not of the train
- Amount of STs resting in Collecting spaces ready to be picked up by the truck
- Amount of STs resting in Collecting spaces not picked up on time by the truck
- Amount of STs resting in Delivery spaces ready to be placed on the train
- Amount of "not-on-time" STs resting in the storage/buffer area ready to be loaded in the train

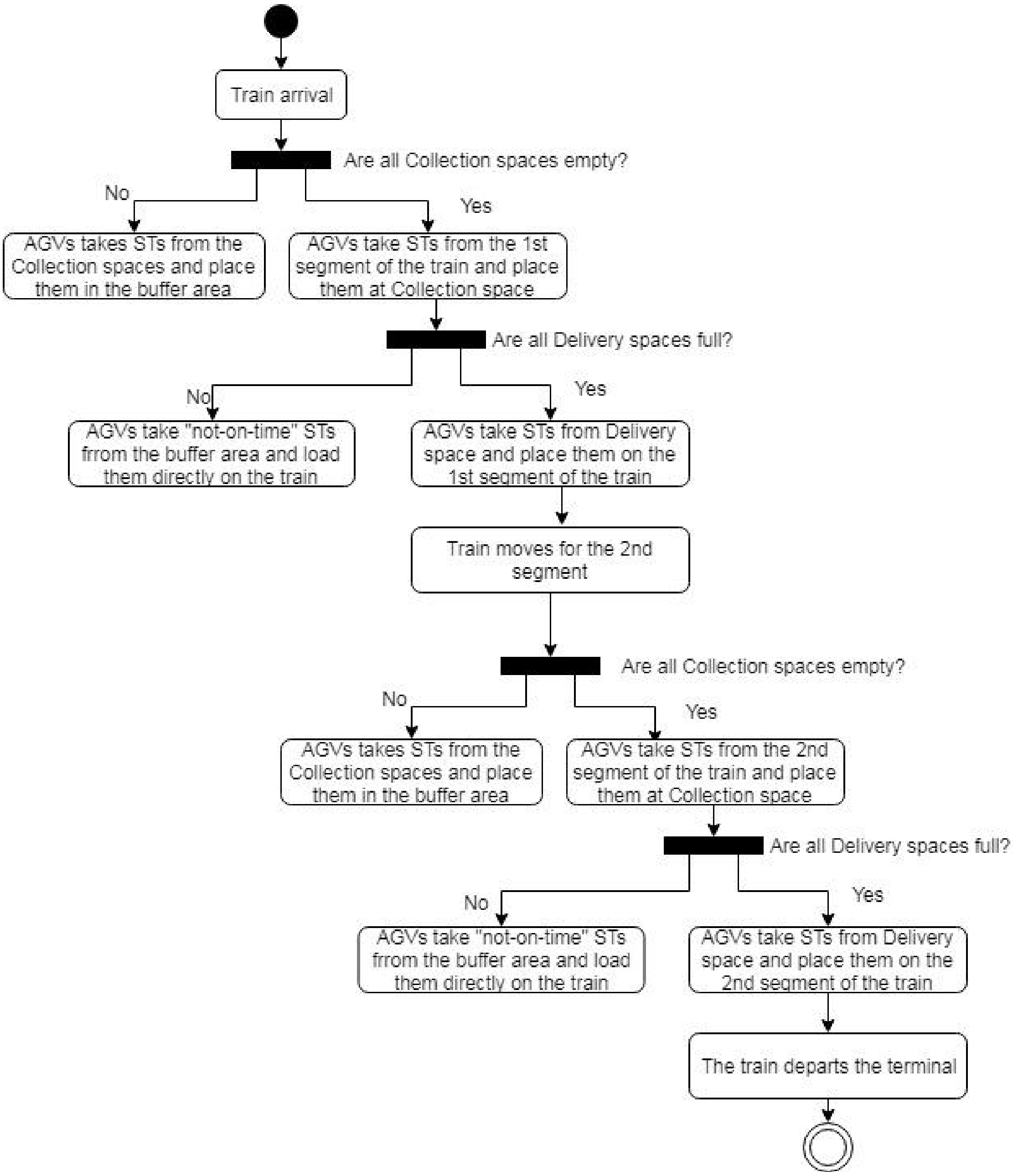

Figure 2-27 AGVs operation

2.9.4. Petri Net

Discrete-event simulation is a significant analysis tool for designing complex terminal systems. Typically, discrete-event simulation models the entities' movement through the system and the changes caused in the state of the system. It is a very general modelling framework; the entities can represent the necessary operations, the shared resources, the synchronized and parallel operations. The new terminal can be seen as a discrete event system. For example, container events include the following:

Arrival. The STs arrives at Delivery stations through trucks.

Transport. The STs are transported by feeder services between C/D stations and parking spaces. A transport event may schedule a subsequent load or unload event if the container is transported to a consignor or a consignee.

Unload. The cargo on the train is unloaded. An unload event schedules a subsequent transport event from the train to a chosen Collection station.

Load. The train is loaded with cargo. A load event schedules a subsequent transport event from Delivery station to the train.

Departure. The STs' departures the station from Collection stations through trucks.

In particular, Petri Nets (PN) are very powerful tools which give a graphical representation of the discrete event systems model. Their basic capability is in the graphical representation and formal analysis of all the processes in a discrete event system. PN are suitable to describe and simulate the dynamic behaviour of complex systems characterized by precedence relations, concurrency, synchronization conflicts and mutual elimination of events.

When compared with other existing formalisms, PN shows the possibility of allowing the identification of critical system conditions (blocking, deadlock, congestion). This can help the system designer in preventing these states, which can critically reduce the terminal performance.

An ordinary PN is a bipartite graph formalized by a four-tuple N = (P, T, A, MO), in which places in set P and transitions in set T are linked by arcs in set A to represent how the system state changes.

The places may contain tokens, which represent certain objects, while the number of tokens may change during the execution of the net. A transition is enabled if each of its input places contains enough tokens and it can fire by consuming tokens from the input places and producing tokens for the output places.

The places are depicted by a circle, transitions by bar and model events changing the state, directed arcs by → and tokens by ● in the schematic representation, as tokens, representing resource-units (AGVs) or entities (STs) in the process, flow through the net.

In certain cases, however, the need arises to also model the timing, not only the structure of a model. For these cases, Timed Petri Nets (TPN) have evolved, where there are transitions that are timed, and possible transitions which are not timed (if there are, transitions that are not timed have a higher priority than timed ones). TPN is a bipartite digraph which consists of two types of nodes: places and transitions connected by directed arcs. It is described by the five-tuple as shown in the following formula:

$$TPN = (P, T, Pre, Post, F)$$

where P represents the set of places with |P| = m, T is the set of transitions with |T| = n, Pre is the pre-incidence matrix with Pre: $P \times T \rightarrow N^{m \times n}$, Post is the post-incidence matrix with Post: $P \times T \rightarrow N^{m \times n}$, and the function F: $T \rightarrow R^{+}$ specifies the timing associated with each transition.

A simulation model has been established based on TPN in this study. In the Petri Net model, places (P) represent resources and capacities or conditions, transitions (T) model inputs, flows, and activities into the terminal and tokens represent intermodal transport units, the STs.

There are three types of transitions used in this model: immediate transition, stochastic transition, and deterministic timed transition.

Corresponding to the operations of the terminal, the TPN model is segmented into 2 submodels which are the overall train cycle model and the cargo-handling model performed by the AGV.

2.9.4.1. Petri Net: Overall train cycle model

The PN model of train arrival and departure process is presented in Figure 2-28 and Table 2-9. Resources are the Waiting Tracks and the U/L track, while temporal entities are the trains.

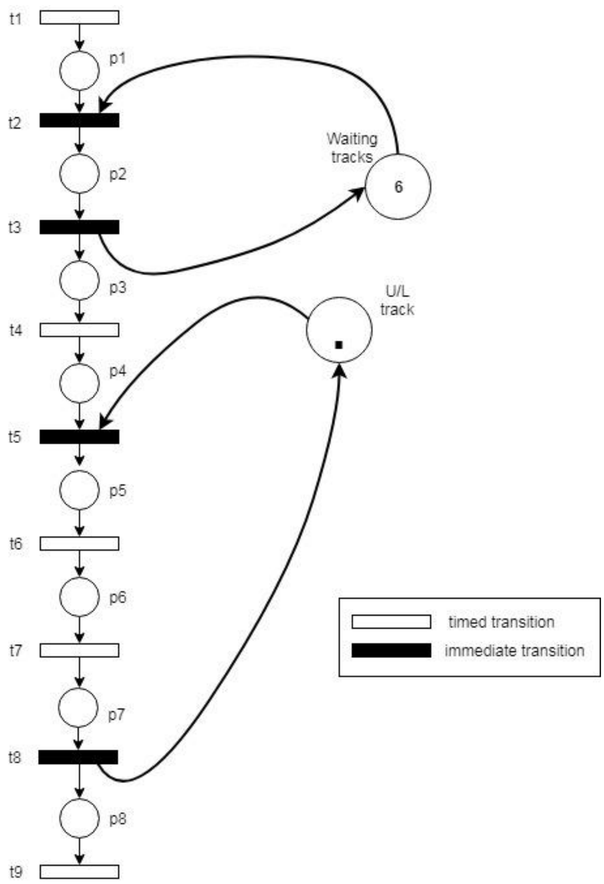

Figure 2-28 PN of the overall cycle process for each train.

Meaning of transactions	Meaning of places
t1: Train arrival to the terminal	p1: Waiting for space in Waiting track
t2: Capture Waiting track	p2: Train stopped in Waiting track
t3: Exit Waiting track	p3: From Waiting track to U/L track
t4: Train translation to U/L track	p4: Waiting for space in U/L track
t5: Capture U/L track	p5: Transport the train to U/L train track
t6: U/L operations for the whole train	p6: Waiting in the U/L train track
t7: Train pre-moving operations	p7: Waiting to depart
t8: Train leaves U/L track	p8: Transport train to departure
t9: Train departure	

Table 2-9 Meaning of transactions and places - Train cycle process.

2.9.4.2. Petri Net: Cargo-handling model

The PN model of the cargo-handling model is presented in Figure 2-29 and Table 2-10. It is a zoom into transaction t6 of the above Overall Cycle Process PN. In the following PN, resources are the AGVs and temporal entities are the STs brought by train or by trucks.

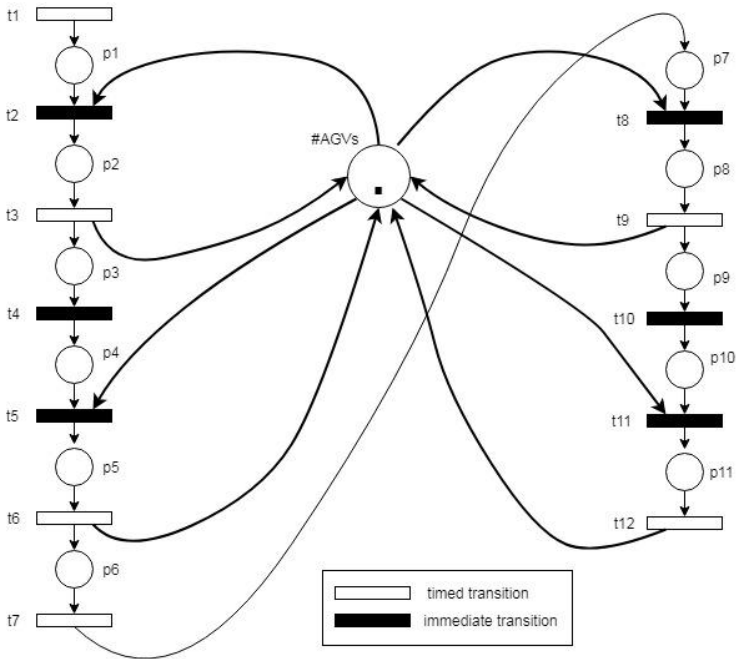

Figure 2-29 PN of the cargo-handling model (Lohr terminal).

Meaning of transactions	Meaning of places
t1: STs arrival to the terminal by train	p1: Waiting space
t2: Capture AGVs	p2: STs 1st seg. transported by AGVs
t3: Unloading STs from the 1st segment	p3: Waiting in the U/L train track
t4: STs arrival by truck (for 1st segment)	p4: STs 1st seg. waiting on D stations
t5: Capture AGVs	p5: STs 1st seg. transported by AGVs
t6: Loading STs to the 1st segment	p6: Waiting in the U/L train track
t7: Train operations & Translation	p7: Waiting in the U/L train track
t8: Capture AGVs	p8: STs 2nd seg. transported by AGVs
t9: Unloading STs from the 2nd segment	p9: Waiting in the U/L train track
t10: STs arrival by truck (for 2nd segment)	p10: STs 2nd seg. waiting on D stations
t11: Capture AGVs	p11: STs 2nd seg. transported by AGVs
t12: Loading STs to the 2nd segment	

Table 2-10 Meaning of transactions and places - Cargo-handling process.

3. RESULTS AND DISCUSSION

In the following section of the work are explained the layout of the simulation, the simulation objects with their correspondent design parameters, the statistics collected from each scenario simulation, the interpretation of these data and future model improvements to better simulate the new intermodal terminal.

3.1. SIMULATION LAYOUT - OBJECTS DESCRIPTION

A CAD document of the Port of Barcelona has been imported (scale 1:10.000) on the platform interface simulation of the *FlexSim* model. [23] See Figure 3-1.

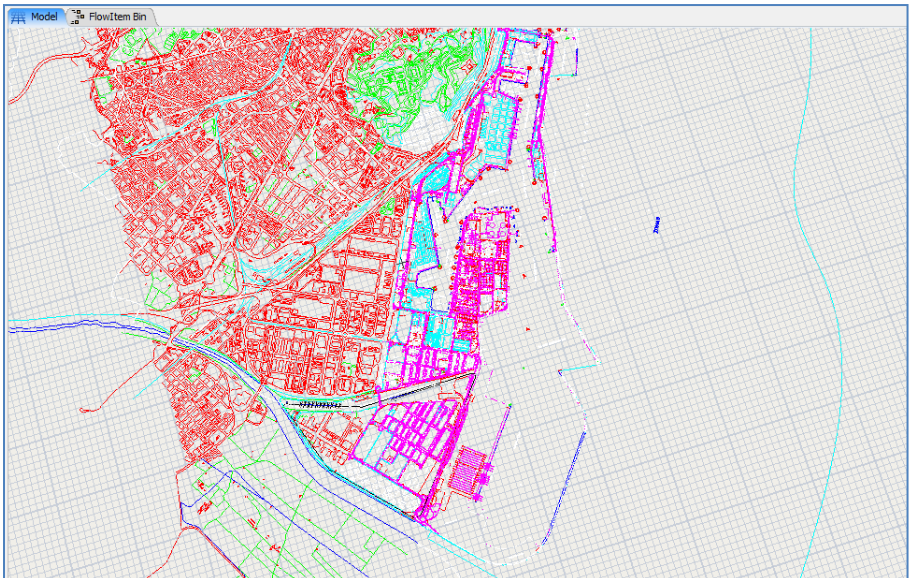

Figure 3-1 FlexSim view. CAD of the Port of Barcelona imported.

As said in previous sections of the present work, the new terminal is located in the southern part of the Port, in the old bed of the Llobregat river. See Figure 3-2.

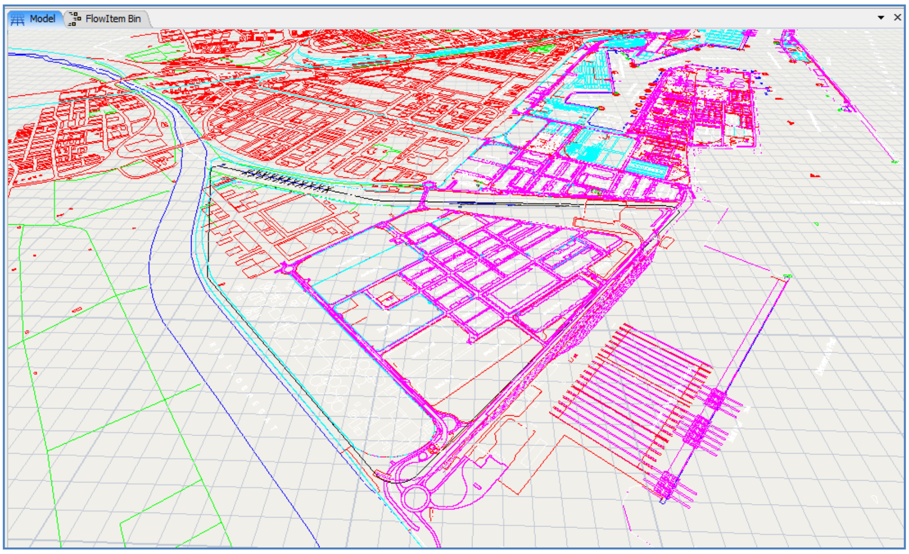

Figure 3-2 FlexSim view. New terminal location in the southern part of the Port.

The new railway access to the Port allows the access of the trains by the river west margin and the exit by the old bed of the river, following a rail triangle in the port area.

The main objects of the model are the following (see Figure 3-3 and 3-4):

- 1 locomotive
- X AGVs
- Waiting lines (queues)
- 3 sources: STs arrival by train (1); STs arrival by truck (2)
- 2 sinks: train departure; trucks departure
- 22 Delivery stations (queues)
- 22 Collection Stations (queues)
- 11 Loading Stations (racks)
- 11 Unloading Stations (racks)

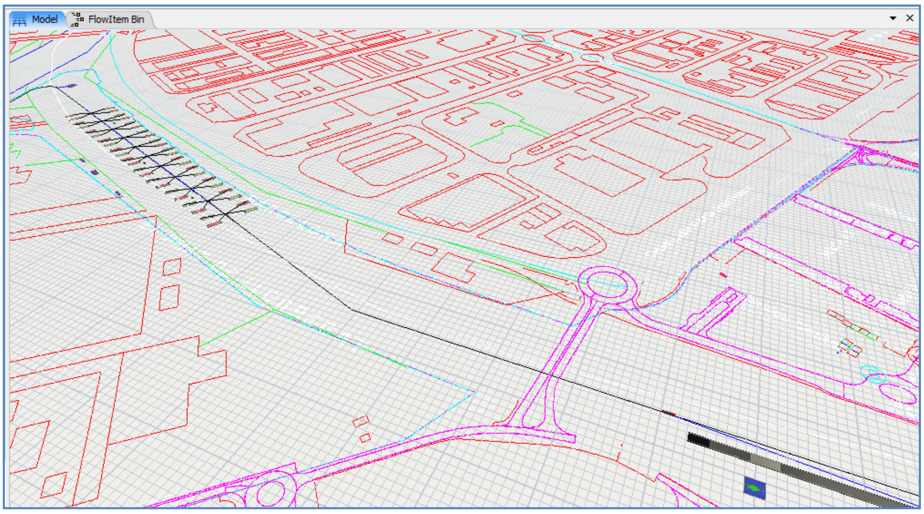

Figure 3-3 FlexSim view. Main objects of the Model.

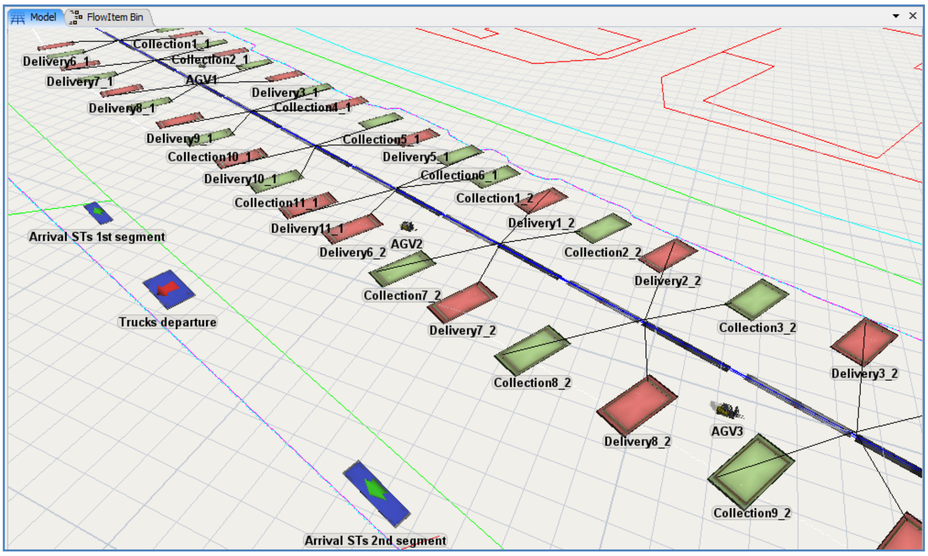

Figure 3-4 FlexSim view. Detail of the U/L track.

See Attachment 3 for the design parameters for each object of the model.

3.2. SCENARIOS ANALYSIS

FlexSim software offers the possibility to collect some statistics from the simulation and display them live on the same interface platform. Those collected statistics can be exported to a .csv delimited file.

The metrics of the new terminal have been gathered for all the studied scenarios:

- 5 trains/day:
    - 2 AGVs
    - 3 AGVs

- 8 trains/day:
    - 4 AGVs
    - 5 AGVs
    - 6 AGVs
    - 7 AGVs

See Figure 3-5 (an example of Scenario "5 trains; 3AGVs") for an example of several visualizations of the cargo volumes.

The pie chart shows the utilization of each AGV disaggregated by the type of task (idle, travel empty, travel loaded, loading and unloading). From the scatter plot, the number of unloaded STs that are picked up by the trucks in the Collection Stations. The line charts show the amount of STs that are processed in the terminal (it is a measurement of the WIP). Finally, the table shows the enter and exit time for each STs.

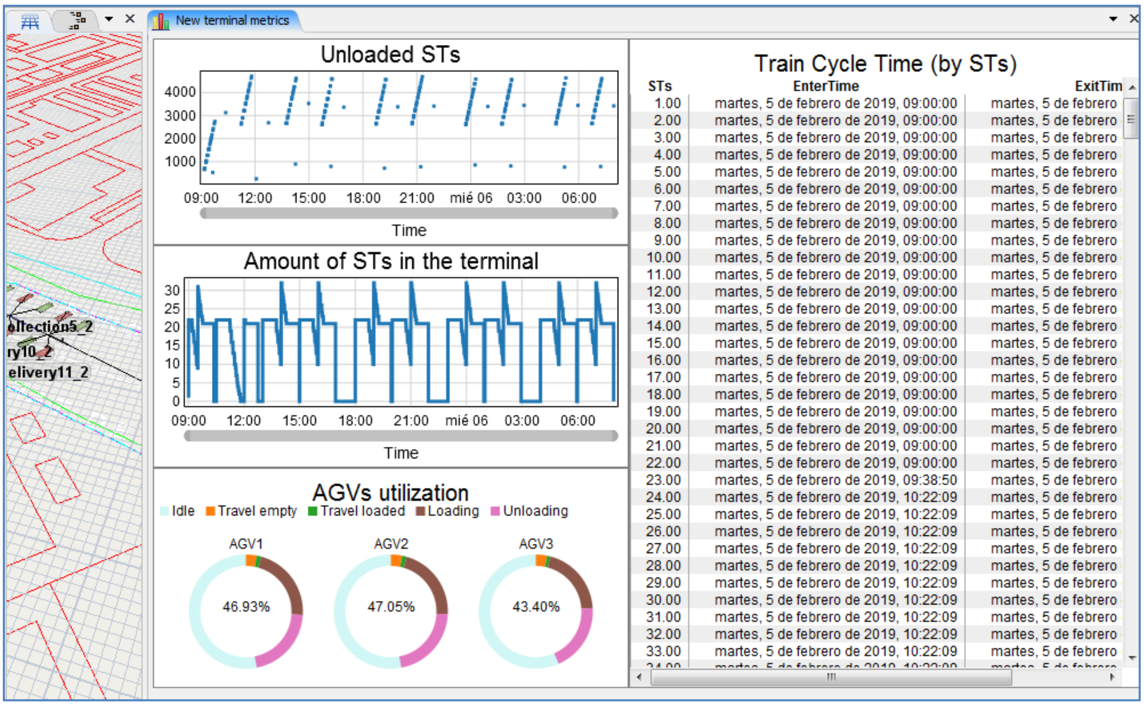

Figure 3-5 FlexSim view. Dashboard of the new terminal metrics.

The following observations (see Figure 3-6) give a more detailed explanation of the scatter plot and the line plot.

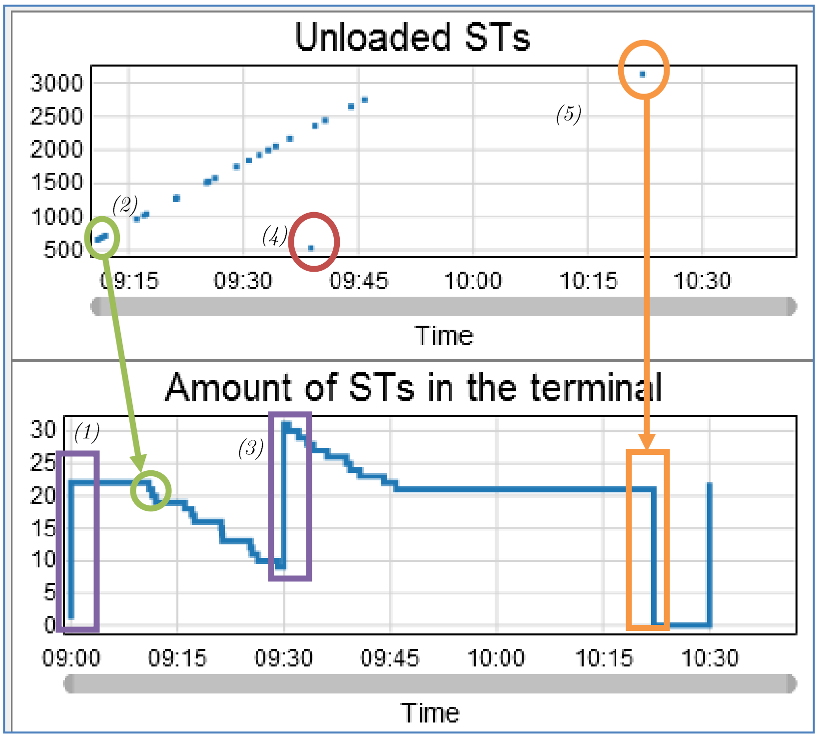

Figure 3-6 Dashboard view on detail.

1) Obs 1: new train arrival (1st segment). 22 STs arrive in the Waiting Line.
2) Obs 2: the three points of the scatter plot correspond to the decrease of 3 STs that have been unloaded and have subsequently departure the terminal by trucks.
3) Obs 3: 2nd segment arrival. 22 STs arrive in the Waiting Line.
4) Obs 4: train departure. 1 ST.
5) Obs 5: train departure. 21 STs

The simulation's driver has been to reduce the amount of waiting time of the trains on the Waiting Tracks. A terminal is more efficient when there are less WIP in the system.

The design parameters that are common for all simulated scenarios are:

Design Parameters (common for all scenarios)	
Level of freight of the trains	100%
Level of freight of the delivery stations	100%
Speed of the trains	4,16m/s (15km/h)
Speed of the AGVs	4,16m/s (15km/h)

Table 3-1 Common design parameters on all simulated scenarios.

The scenario of 5 trains per day has been simulated with 2 and 3 AGVs while the scenario of 8 trains per day has been simulated with 4, 5, 6 and 7 AGVs. For each case the following metrics have been gathered in a context of one regular working-day:

- Average waiting time of the train on the waiting track;
- The maximum content of trains on the waiting track;
- Cycle time[8] for each train;
- AGV utilization;
- Unloaded time for each ST carried by train;
- Amount of STs in the system (WIP);

3.2.1. New terminal metrics: 5 trains per day

- 2 AGVs

Average Waiting Time in Waiting Track		
s	min	h
8570,0	142,8	2,4

max content in Waiting Track	2 trains

Table 3-2 Waiting track statistics. Scenario 5 trains/day and 2AGVs.

Train	STs	EnterTime	ExitTime	Cycle Time
1	44	05/02/2019 9:00	05/02/2019 12:42	3:42:00
2	44	05/02/2019 13:00	05/02/2019 17:44	4:44:00
3	44	05/02/2019 18:00	05/02/2019 22:34	4:34:00
4	44	05/02/2019 23:00	06/02/2019 3:57	4:57:00
5	44	06/02/2019 4:00	06/02/2019 10:56	6:56:00
Average				**4:58:36**

Table 3-3 Cycle time. Scenario 5 trains/day and 2AGVs.

[8] *Cycle time is the total amount of time required from the arrival of a train to its departure.*

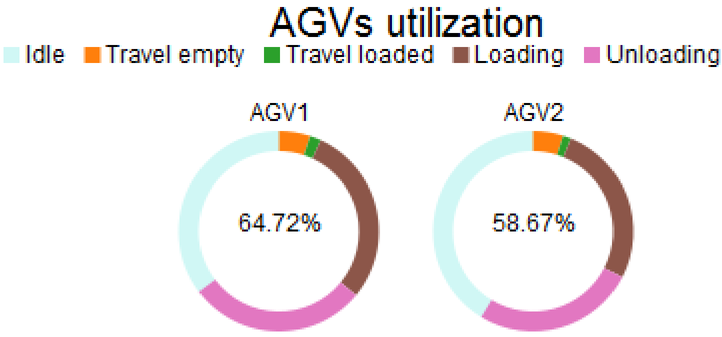

Table 3-4 AGVs' utilization. Scenario 5 trains/day and 2AGVs.

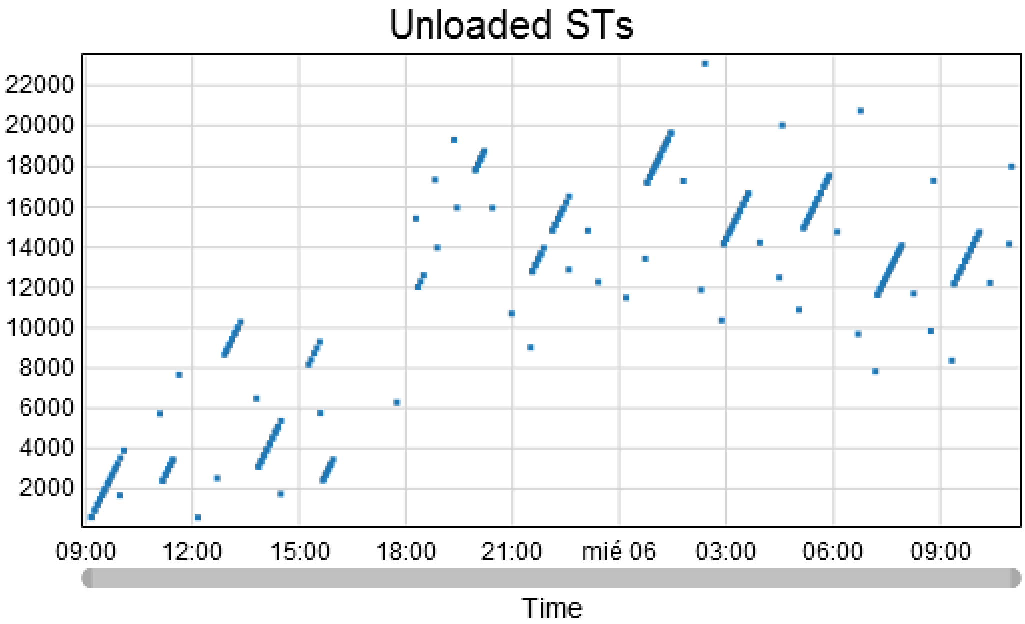

Table 3-5 Unloaded STs. Scenario 5 trains/day and 2AGVs.

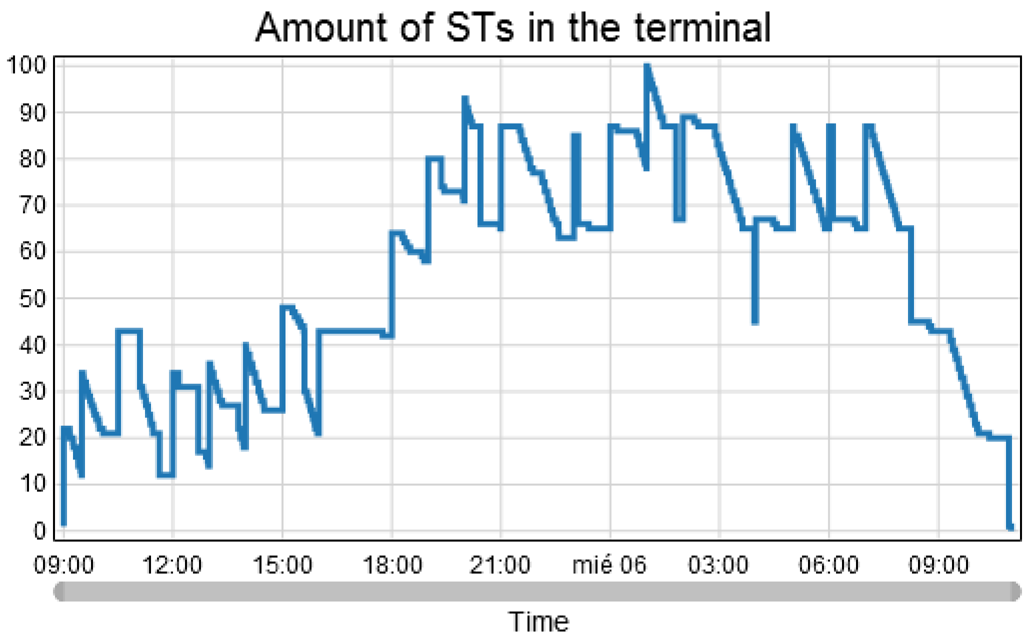

Table 3-6 Amount of STs in the terminal (WIP). Scenario 5 trains/day and 2AGVs.

- 3 AGVs

Average Waiting Time in Waiting Track		
s	min	h
1761,5	29,4	0,5

max content in Waiting Track	1 train

Table 3-7 Waiting track statistics. Scenario 5 trains/day and 3AGVs.

Train	STRs	EnterTime	ExitTime	Cycle Time
1	44	05/02/2019 9:00	05/02/2019 12:44	3:44:49
2	44	05/02/2019 13:00	05/02/2019 16:56	3:56:06
3	44	05/02/2019 18:00	05/02/2019 21:56	3:56:54
4	44	05/02/2019 23:00	06/02/2019 2:57	3:57:26
5	44	06/02/2019 4:00	06/02/2019 7:57	3:57:03
Average				**3:54:28**

Table 3-8 Cycle time. Scenario 5 trains/day and 3AGVs.

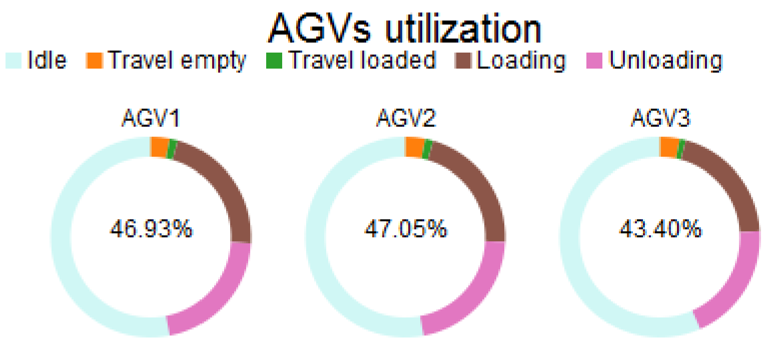

Table 3-9 AGVs' utilization. Scenario 5 trains/day and 3AGVs.

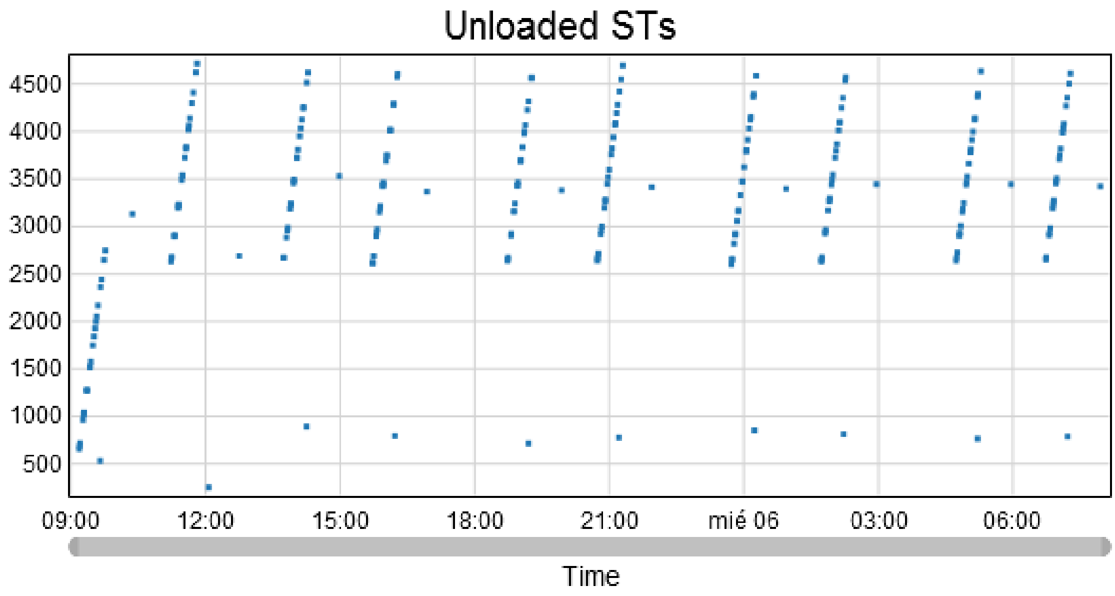

Table 3-10 Unloaded STs. Scenario 5 trains/day and 3AGVs.

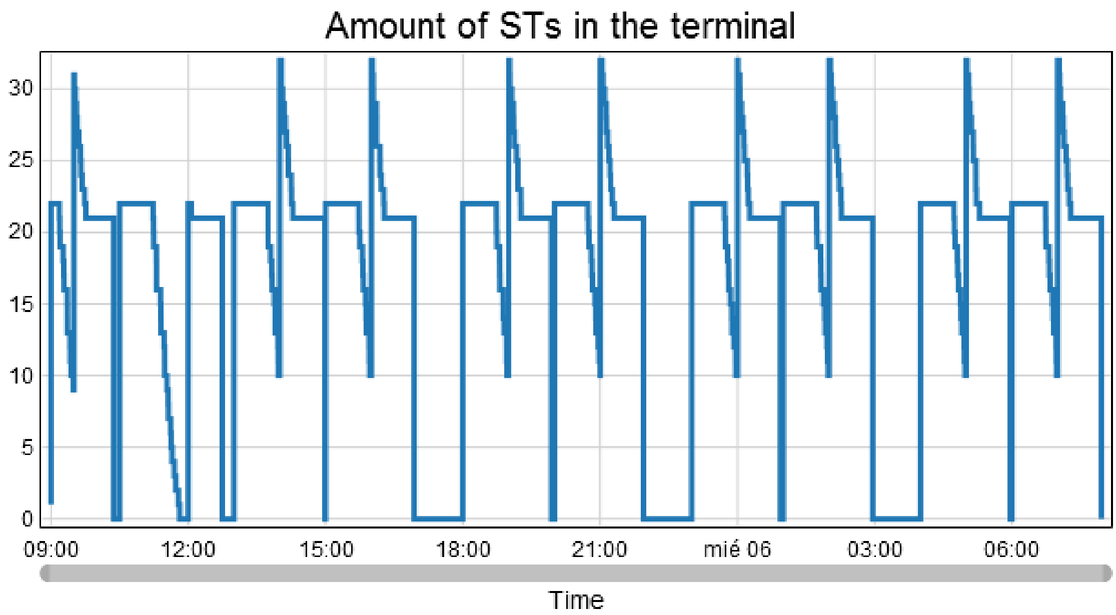

Table 3-11 Amount of STs in the terminal (WIP). Scenario 5 trains/day and 3AGVs.

3.2.2. New terminal metrics: 8 trains per day

- 4 AGVs

Average Waiting Time in Waiting Track		
s	min	h
1455,7	24,3	0,4

max content in Waiting Track	1 train

Table 3-12 Waiting track statistics. Scenario 8 trains/day and 4AGVs.

Train	STRs	EnterTime	ExitTime	Cycle Time
1	44	05/02/2019 9:00	05/02/2019 11:34	2:34:00
2	44	05/02/2019 11:48	05/02/2019 14:28	2:40:00
3	44	05/02/2019 15:03	05/02/2019 17:30	2:27:00
4	44	05/02/2019 18:07	05/02/2019 20:37	2:30:00
5	44	05/02/2019 21:13	05/02/2019 23:40	2:27:00
6	44	06/02/2019 0:16	06/02/2019 2:40	2:24:00
7	44	06/02/2019 3:16	06/02/2019 5:43	2:27:00
8	44	06/02/2019 6:20	06/02/2019 9:29	3:09:00
Average				**2:34:45**

Table 3-13 Cycle time. Scenario 8 trains/day and 4AGVs.

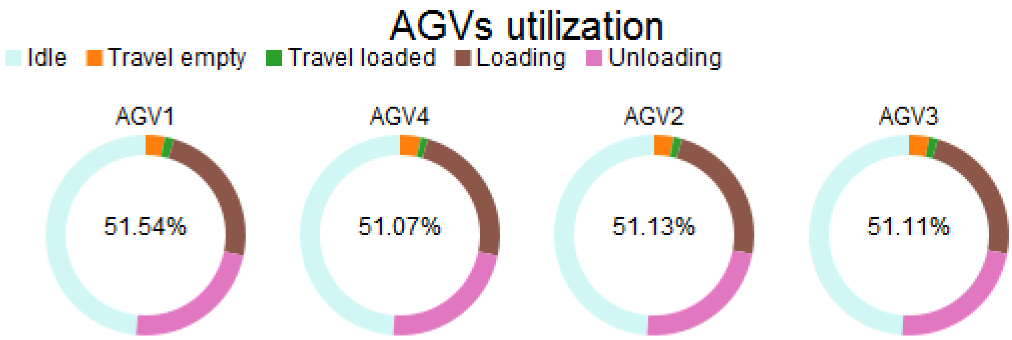

Table 3-14 AGVs' utilization. Scenario 8 trains/day and 4AGVs.

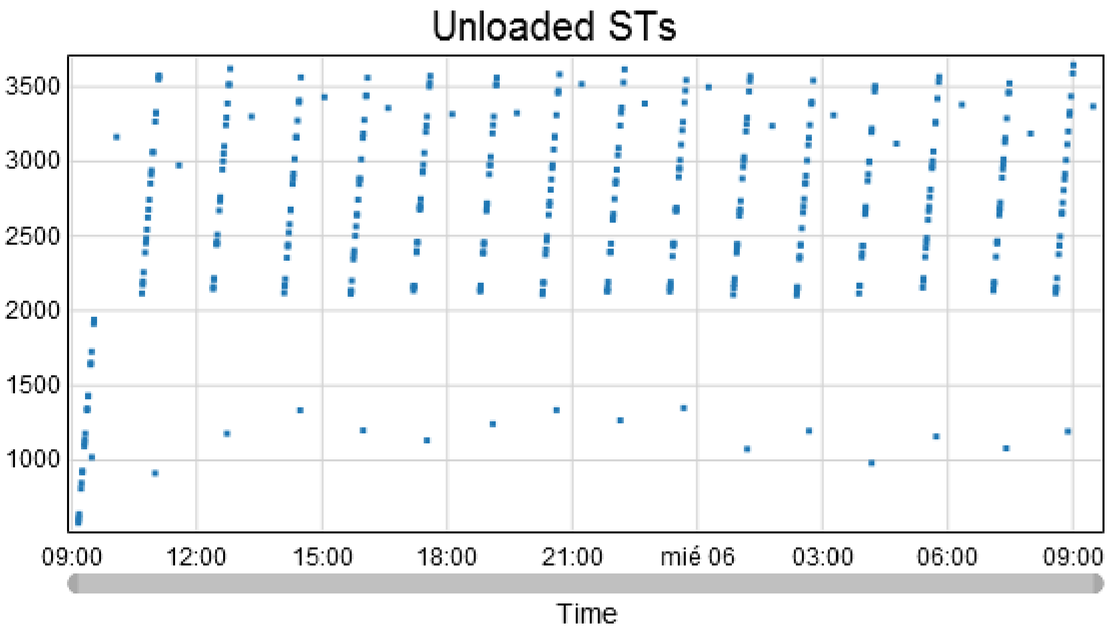

Table 3-15 Unloaded STs. Scenario 8 trains/day and 4AGVs.

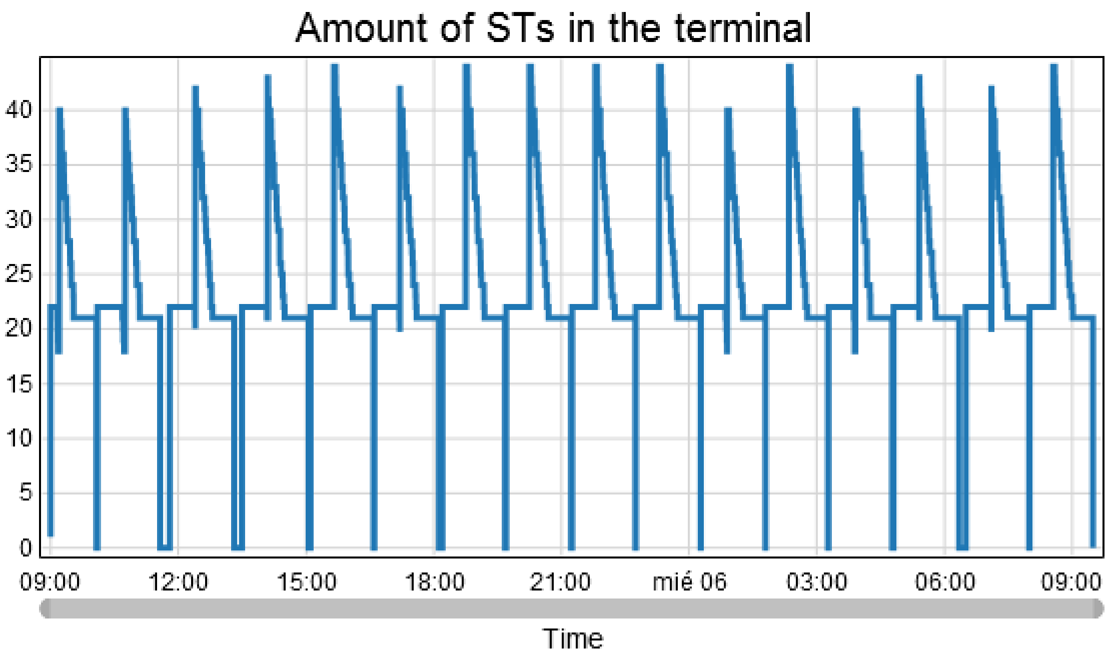

Table 3-16 Amount of STs in the terminal (WIP). Scenario 8 trains/day and 4AGVs.

- 5 AGVs

Average Waiting Time in Waiting Track		
s	min	h
1455,7	24,3	0,4

max content in Waiting Track	1 train

Table 3-17 Waiting track statistics. Scenario 8 trains/day and 5AGVs.

Train	STRs	EnterTime	ExitTime	Cycle Time
1	44	05/02/2019 9:00	05/02/2019 11:38	2:38:08
2	44	05/02/2019 12:00	05/02/2019 14:56	2:56:17
3	44	05/02/2019 15:00	05/02/2019 17:56	2:56:21
4	44	05/02/2019 18:00	05/02/2019 20:56	2:56:33
5	44	05/02/2019 21:00	05/02/2019 23:56	2:56:47
6	44	06/02/2019 0:00	06/02/2019 2:55	2:55:46
7	44	06/02/2019 3:00	06/02/2019 5:56	2:56:27
8	44	06/02/2019 6:00	06/02/2019 8:55	2:55:33
Average				**2:53:59**

Table 3-18 Cycle time. Scenario 8 trains/day and 5AGVs.

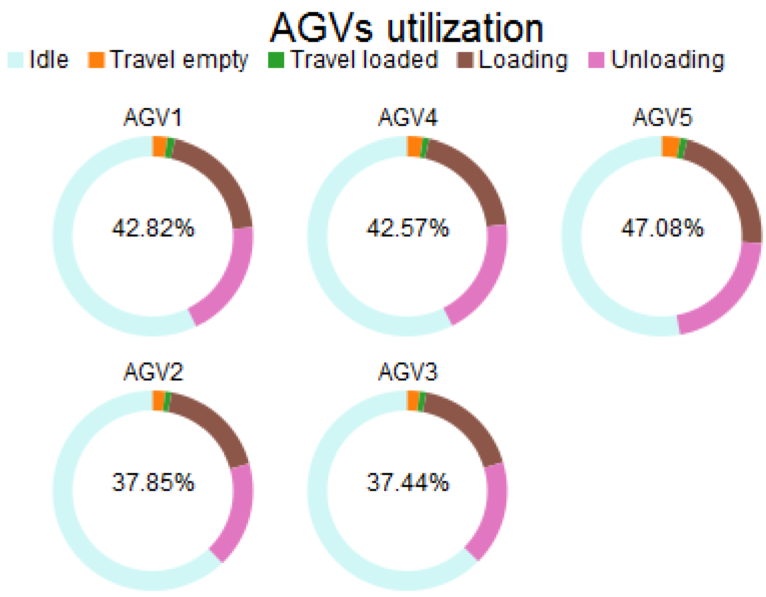

Table 3-19 AGVs' utilization. Scenario 8 trains/day and 5AGVs.

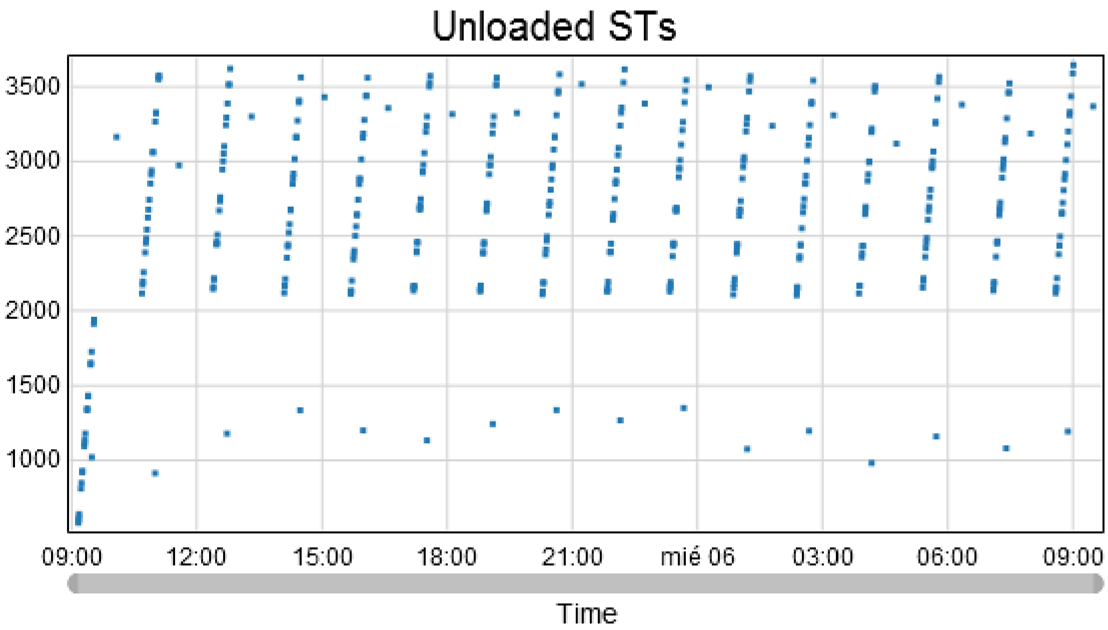

Table 3-20 Unloaded STs. Scenario 8 trains/day and 5AGVs.

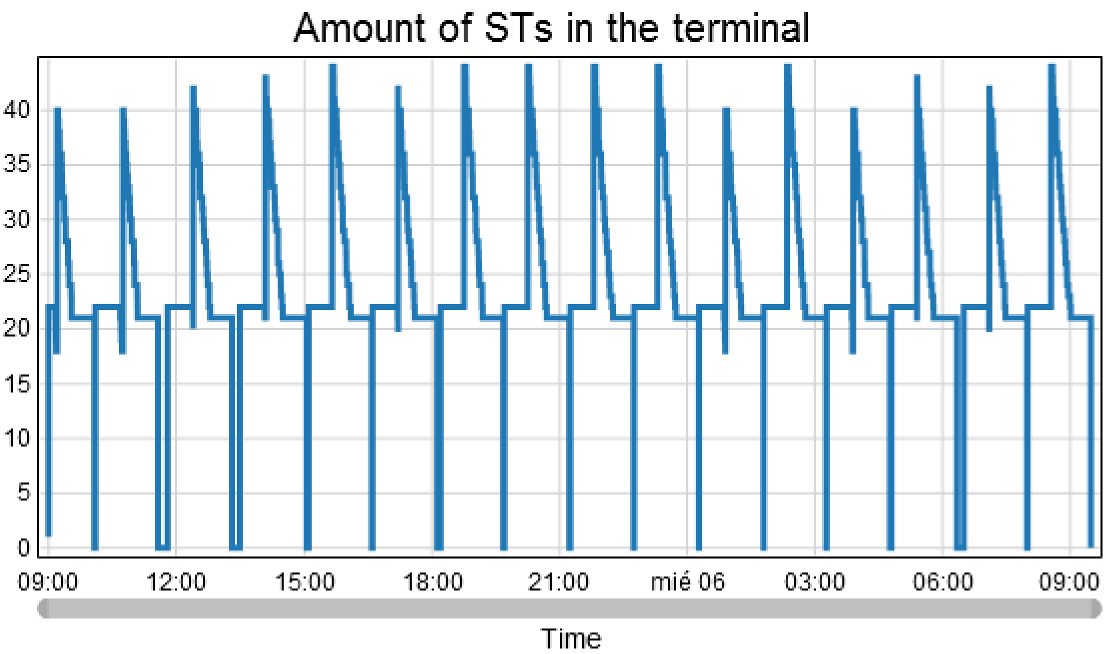

Table 3-21 Amount of STs in the terminal (WIP). Scenario 8 trains/day and 5AGVs.

- 6 AGVs

Average Waiting Time in Waiting Track		
s	min	h
1455,7	24,3	0,4

max content in Waiting Track	1 train

Table 3-22 Waiting track statistics. Scenario 8 trains/day and 6AGVs.

Train	STRs	EnterTime	ExitTime	Cycle Time
1	44	05/02/2019 9:00	05/02/2019 11:37	2:37:40
2	44	05/02/2019 12:00	05/02/2019 14:57	2:57:43
3	44	05/02/2019 15:00	05/02/2019 17:45	2:45:32
4	44	05/02/2019 18:00	05/02/2019 20:42	2:42:37
5	44	05/02/2019 21:00	05/02/2019 23:44	2:44:46
6	44	06/02/2019 0:00	06/02/2019 2:45	2:45:30
7	44	06/02/2019 3:00	06/02/2019 5:42	2:42:20
8	44	06/02/2019 6:00	06/02/2019 8:44	2:44:24
Average				**2:45:04**

Table 3-23 Cycle time. Scenario 8 trains/day and 6AGVs.

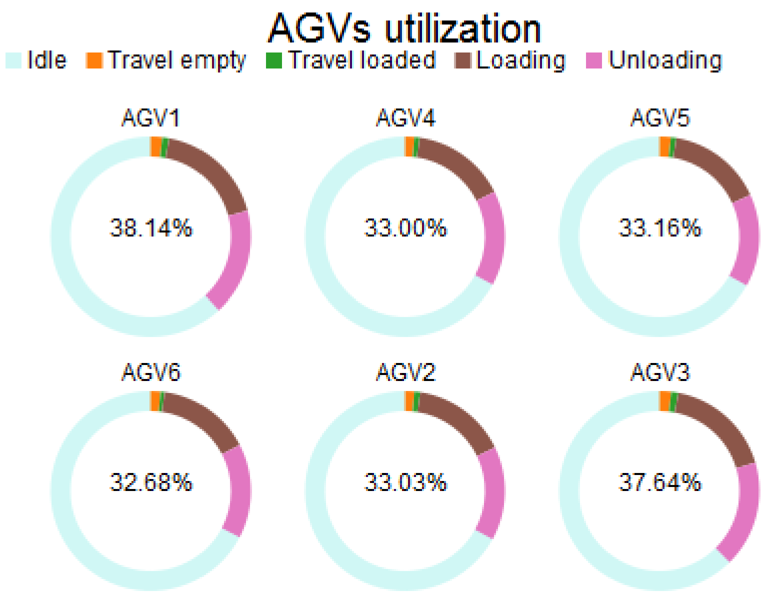

Table 3-24 AGVs' utilization. Scenario 8 trains/day and 6AGVs.

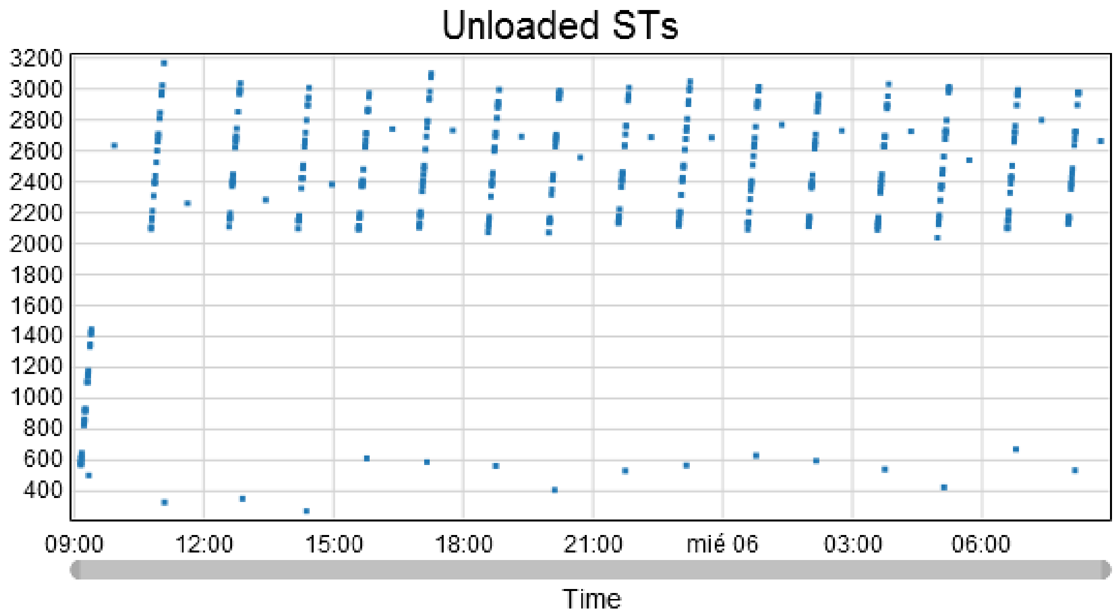

Table 3-25 Unloaded STs. Scenario 8 trains/day and 6AGVs.

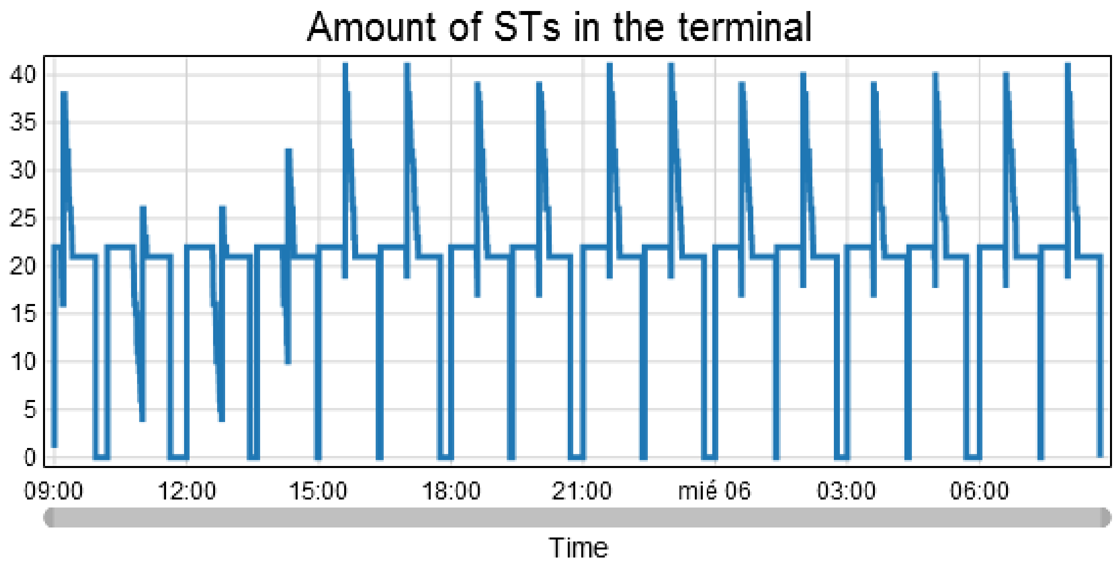

Table 3-26 Amount of STs in the terminal (WIP). Scenario 8 trains/day and 6AGVs.

- 7AGVs

Average Waiting Time in Waiting Track		
s	min	h
1455,7	24,3	0,4

max content in Waiting Track	1 train

Table 3-27 Waiting track statistics. Scenario 8 trains/day and 7AGVs.

Train	STRs	EnterTime	ExitTime	Cycle Time
1	44	05/02/2019 9:00	05/02/2019 11:36	2:36:52
2	44	05/02/2019 12:00	05/02/2019 14:54	2:54:57
3	44	05/02/2019 15:00	05/02/2019 17:40	2:40:49
4	44	05/02/2019 18:00	05/02/2019 20:37	2:37:00
5	44	05/02/2019 21:00	05/02/2019 23:41	2:41:55
6	44	06/02/2019 0:00	06/02/2019 2:41	2:41:18
7	44	06/02/2019 3:00	06/02/2019 5:41	2:41:09
8	44	06/02/2019 6:00	06/02/2019 8:08	2:08:37
Average				**2:37:50**

Table 3-28 Cycle time. Scenario 8 trains/day and 7AGVs.

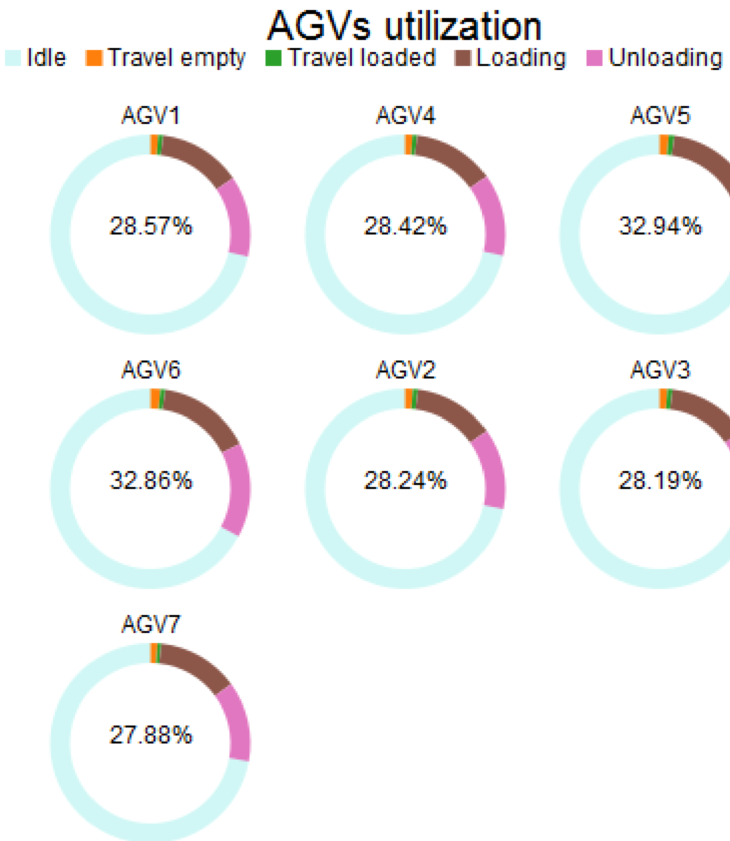

Table 3-29 AGVs' utilization. Scenario 8 trains/day and 7AGVs.

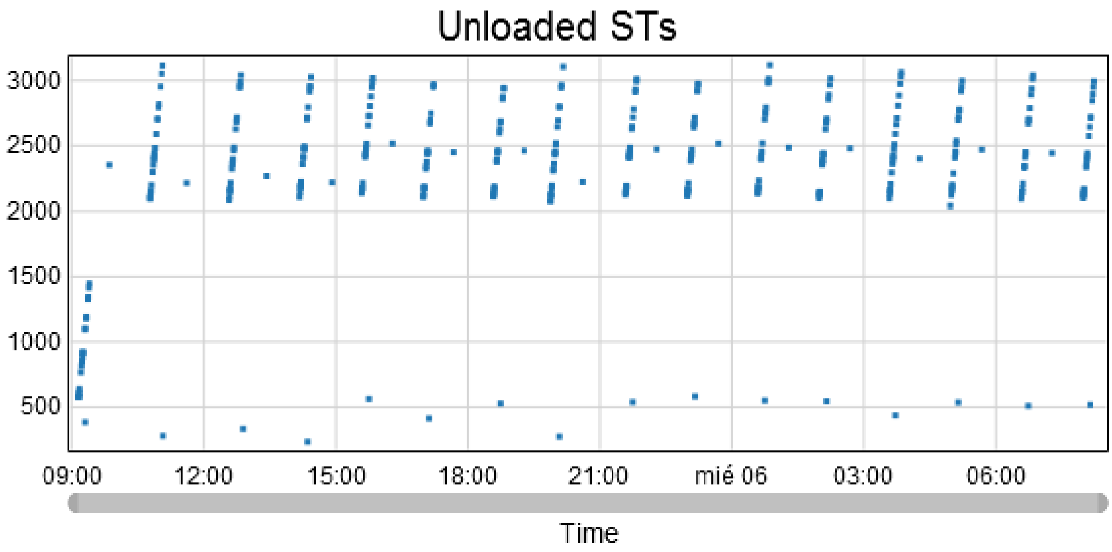

Table 3-30 Unloaded STs. Scenario 8 trains/day and 7AGVs.

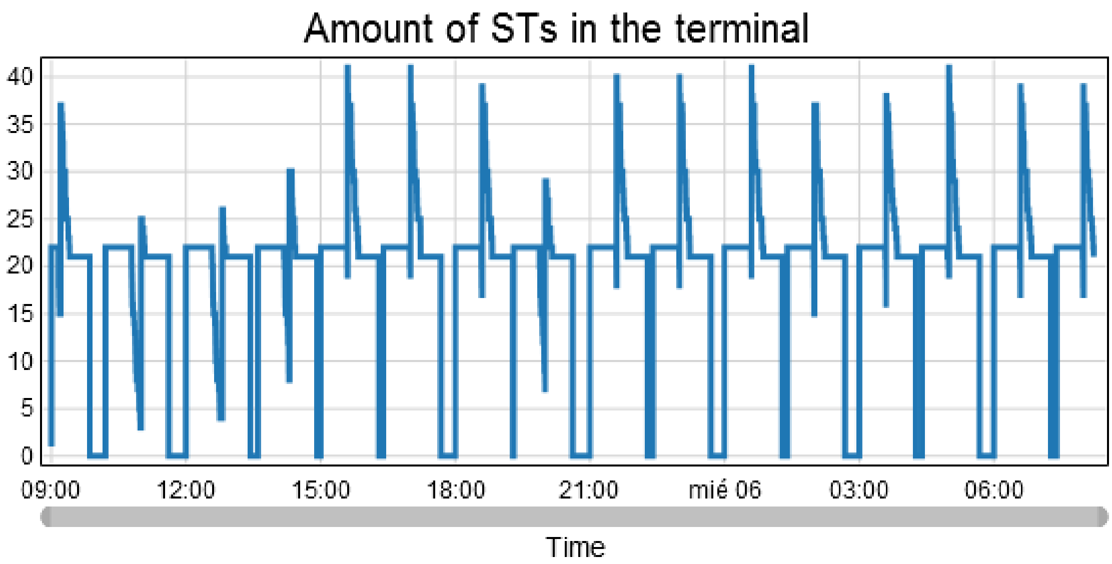

Table 3-31 Amount of STs in the terminal (WIP). Scenario 8 trains/day and 7AGVs.

3.3. RESULTS INTERPRETATION

The following Table 3-32 summarizes the main factors of all the analyzed scenarios for the different amount of AGVs. On it, it has been added the field Margin, which is the calculation of the amount of free time between the departure of the last train (5th or 8th train) and the arrival of the first train of the next working-day, knowing that it will arrive at the terminal at 9:00 in the morning.

	Waiting Track					
	Average time [h]	Max. Content	Average Cycle time per train	Exit time last train	Margin with Enter time first train (9:00)	Average AGVs utilization
5 trains/day						
2 AGVs	2,4	2	4:58:36	10:56 (+1 day)	(1:56)	61,71%
3 AGVs	0,5	1	3:54:28	7:57 (+1 day)	1:03	45,82%
8 trains/day						
4 AGVs	0,4	1	2:34:45	9:29 (+1 day)	(0:29)	51,21%
5 AGVs	0,4	1	2:53:59	8:55 (+1 day)	0:05	41,55%
6 AGVs	0,4	1	2:45:04	8:44 (+1 day)	0:16	34,60%
7 AGVs	0,4	1	2:37:50	8:08 (+1 day)	0:52	29,58%

Table 3-32 Summarized statistics for all scenarios.

The decision regarding the optimum amount of AGVs for each scenario depends on many factors.

For the scenario of 5 trains per day, the determining factor is the margin between the departure of the last train (day 0) and the arrival of the first train (day 1). As seen in the table, for the case of 2AGVs, there is no free time. In contrast, for 3AGVs, the margin amounts to 1 hour as the departure of the last train is at 7:57 of day 1 while the arrival of the first one for day 1 is at 9:00.

Moreover, for the 2AGVs' situation, the average waiting time of the trains waiting to be processed is 2,4h., 0,5h for 3AGVs. As reducing the waiting time of the trains is one of the main objectives of the present simulation, this last factor was crucial to determine that 3AGVs is the optimal amount of task executers in the scenario of 5 trains per day.

In this situation, the average cycle time for each train is almost 4 hours and the average AGVs' utilization is 45,81%.

For the scenario of 8 trains per day, the factor that makes discard 4AGVs is the margin, which is negative, which means that there is an overlap of around 30min between the last train of day 0 and the first train of day 1 that might generate further delays in the future performances of the terminal.

Checking the other options, the two that offer a better balance between margin, cycle time and AGVs utilization are the situations of 5 and 6 AGVs. The situation of 7AGVs is discarded as the average AGVs' utilization is slightly under 30%.

Both cases of 5 and 6 AGVs are optimal. However, considering that all simulations have been performed with a maximum scenario of 100% capacity, which in reality capacity will be under this value, the option of 5AGVs might be the perfect compromise between cycle time, margin and average AGVs utilization.

See Attachment IV for a more detailed simulation statistics of the best scenarios: 3AGVs for 5trains per day and 5AGVs for 8 trains per day.

On those more detailed tables is stated that the average operation time for the trains between the 1st and 2nd segment is over the minimum required of 30min. For the case of 3AGVs, it is 3046 s (50,7 min), whereas for the 5AGVs is 2419,7 s (40,3 min).

The average unloading and loading time for each train in the 3AGVs situation are around 35 and 37min respectively. For the 5AGVs situation, the unloading and loading average time is around 25min.

4. CONCLUSIONS

Transport is responsible directly and indirectly (energy, infrastructure, etc.) for about 25% of CO_2 emissions, which contribute to global warming and to changes in climate that have major impacts on those same transports. It is recognized and scientifically proven that climate change hazards can affect the life-span and effectiveness or even destroy infrastructure in the transport sector with serious social and economic consequences.

The 2015 Paris Climate Conference (or COP21) has validated an international agreement on climate, applicable to all countries, setting a goal of limiting global warming between 1.5 °C and 2 °C by 2100.

European Union was strongly involved in the success of this event. With respect to the issue of climate change, the Mediterranean Corridor, like the TEN-T network as a whole, has to face two different types of challenges:

- The mitigation of the impacts of transport on climate change: the Corridor has to be an instrument for the reduction of GES emissions due to the transport sector. This can be achieved through a modal shift towards low-emission modes and through the deployment of new, carbon-efficient technologies.
- The adaptation of the corridor's infrastructure and services to climate change: climate change is underway, and a number of its consequences can already be seen and they will increase in the future. These disturbances are inevitable because of the inertia of the climate system and require adaptation. This adaptation must be considered as an indispensable complement to the mitigation actions.

The implementation of the TEN-T Mediterranean Core Network Corridor will provide a significant contribution to the necessary mitigation of the environmental impacts of transport in Europe. The reduction of GHG, NOx, SOx & particles emissions is primarily linked with a modal shift from road to rail and maritime, in particular for international freight transport.

The Corridor also contributes to more efficient rail transport, with total electrification and higher load factors thanks to the implementation of the TEN-T standards. It generates growth and positive job impacts on the related countries. The Corridor also mitigates other environmental impacts such as noise and air pollution.

The Mediterranean Corridor shall provide economically efficient and clean transport options to the flows of passengers and goods between those territories as well as the other Countries that will take benefit from the Corridor's development for their international flows (e.g. Balkan countries, Ukraine etc. on the Eastern side).

Especially in relation to Western Balkans regions, but also considering Northern African and Eastern European countries, the Corridor should include the links with third countries. The important growth potential of these territories, where the transport connections remain still very weak, requires particular attention in terms of the development of transport infrastructure as well as of regulatory reforms and convergence.

While the environmental impacts of the Corridor should be globally very positive, some negative impacts, often local or limited in time, need to be addressed and reduced.

The main urban areas along the Corridor constitute sometimes serious bottlenecks for rail hampering not only local and regional traffic but also restricting severely international traffic. Particular attention needs to be paid to urban nodes which form the crossing points with other core network Corridors, in order to allow a seamless flow of high-speed passengers and freight flows. This concerns first of all the major nodes like Madrid, Lyon and Milan, but also Verona, Venice and Budapest.

For the optimum performance of the Mediterranean Corridor by 2030, bottlenecks in Barcelona and Turin Areas should be addressed. For the Barcelona bottleneck, the Spanish Ministry of Development should keep their promises regarding the adaptation of Spanish rail tracks to the UIC gauge and to train length of 750m and should solve the problem of lack of capacity in certain lines, as the congested Martorell-Castellbisbal. For the Turin bottleneck, once unblocked the political situation regarding the construction of the Turin-Lyon line, constructions works should start in order to deliver the project by 2030.

In Europe, major investments have been made over the last few years, all resulting in significant growth in the use of ports and of their influence areas (hinterlands).

In order to complete the hinterland connections and therefore achieving the highest returns from the measures implemented, it is necessary to complete the pending road and railway accesses. In particular, as regard rail, proper connections with hinterland are the most relevant critical issue.

Intermodal connections are very important in this context because traffic does not usually start and end on a Rail Freight Corridor exclusively, but in other transport modes.

Rail connection should be addressed in terms of:

1) developments inside the port in order to connect the different terminals with the port rail access;

2) connection between port and rail network (i.e. “last mile connection”);

3) long-distance connections because of their bottlenecks and missing sections affect the development of services with origin and destination in the port.

Projects fomenting the construction of efficient intermodal terminals on strategic sites, as the Port of Barcelona, to connect both local and European scenes, acquire major importance as they are part of the EU project of harmonizing the European transport of freight in a sustainable and optimal way.

In this context of linking Europe is framed Catalonia. Catalonia is an economic motor that cannot base its growth on domestic demand and, as a consequence, it is one open economy abroad. In this economic model strategy, the sector Logistics becomes key for its present and future development.

Barcelona and its metropolitan area enjoy the necessary potential to become a South-Europe logistics hub on a continental scale to meet this need, due to its economic and demographic dimension, its geographical location and its provision of infrastructures.

Barcelona is becoming an increasingly attractive destination for freight shippers keen to make use of its growing rail freight infrastructure.

The Port of Barcelona is currently not the most important Spanish port, having been overtaken by the ports of Valencia (4,79 million TEUs) and Algeciras (4,30 million tonnes). However, Barcelona has the competitive advantage of having railway connections with France using central European gauge track and being able to handle 750m trains. Its "Spanish rivals" are not connected with the Mediterranean corridor yet.

The type of intermodal terminal proposed in the present work is a Lohr railway terminal. The key advantage of the Lohr system is that it opens up the rail transport market to all semi-trailers (approx. 97% of the market). This causes some knock-on effects. Firstly, carbon emissions for rail freight are significantly lower than for equivalent road carriage, so an increased emphasis on railways is a big step towards the decarbonisation of transport. Secondly, for long distance overland transports of above 500 kilometres and in particular through the Alps, the railways are faster, cheaper and more efficient. Thirdly, shifting trucks from road to rail also decongests the road network which is a benefit for the society as a whole.

The main disadvantage of the Lohr System is that it requires a relatively heavy rail wagon, which increases the energy consumption and therefore operational costs. As seen in the present project, the terminals are built in a customized way and, due to the required number of U/L stations and the needed space to manoeuvre, are large in size. This makes it difficult to find locations in densely industrialized zones and leads to a big initial investment fixed at a particular position which equals risk.

An obstacle regarding the intermodal rail/road terminals is represented by the Information Technology systems currently installed in those terminals: while maritime terminals have been investing in the IT sector for a long time, rail/road terminals have not done the same. The consequence is that often data, such as the physical location of the ST on the yard, which are necessary to implement effective management strategies, are not available.

There are some signals that things are changing. The pressure of freight traffic on European roads is pushing the European Community to invest and promote intermodal transport as a viable alternative to long-haul road transport. The present project is one of the outcomes of this policy and we expect that this and other demonstrative projects will show the terminal operators ways to invest to improve the efficiency of their management procedures, thus enhancing their competitiveness with respect to road-only freight.

Regarding the new terminal site, after performing a PESTEL and SWOT analysis, taking into consideration all the terminal needs, the additional intermodal terminal requirements, the stakeholders' mutual interests, the new rail access planned along the old course of the Llobregat River and the available room in this mentioned area, made choose the old course of Llobregat River as the location site for the new terminal.

The new terminal could start operating once the Ministry of Development, through ADIF, completes the new rail access by the river margin and the rail triangle in the port area.

The objective of simulating an intermodal terminal building a model on *FlexSim*, studying two scenarios to better set the number of task executers and collecting relevant statistics has been obtained.

For a situation of full capacity of trains and delivery stations, in the scenario of 5 trains per day, the optimum amount of AGVs is 3 with a cycle time per train of 4 hours and a margin time of 1 hour, while for the scenario of 8 trains per day, the optimum amount of AGVs is 6 with a cycle time of 2:45h and a margin of 15min. Those results are in line with the theoretical ones found in previous sections of the present work. For the first proposed scenarios of 5 daily trains and 3 AGVs, the AGVs utilization is 45% on average, while for 8 daily trains and 6 AGVs is 35% on average.

One of the achieved objectives of this project was to link different conceptual and practical parts implied in the construction of a new intermodal terminal to be able to understand how other non-logistic factors might impact the construction of a new intermodal terminal. With the present work has been recognized that economic, politic, social and environmental factors directly impact the characteristics, location and performance of an intermodal terminal.

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LIST OF ATTACHMENTS

The following information is part of the attachments of the project. In this section, it is included:

- AI. Rail track characteristics in Barcelona and Turin Areas
- AII. New Southern Rail Access to the Port of Barcelona – Phase 2
- AIII. Design parameters for each object of the model
- AIV. Detailed simulation statistics of the best scenarios

AI. Rail track characteristics in Barcelona and Turin Areas

Rail line characteristics in the Barcelona Area [9]:

	SECTION LENGHT	LINE TYPE			TRACK GAUGE		DOUBLE TRACK	MAX. TRAIN LENGHT INCL. TRACTION									AXLE LOAD			LOAD PER METRE			TRAIN SPEED				LOADING GAUGE		POWER SUPPLY			SIGNALING SYSTEM								GRADIENT	
	km	PRINCIPAL ROUTE	DIVERSIONARY	CONNECTING/FEEDER	1435 mm	1668 mm		350 m	450 m	500 m	550 m	575 m	600 m	625 m	650 m	750 m	20,0 T/axle	21,0 T/axle	22,5 T/axle	6,4 T/m	7,2 T/m	8,0 T/m	v ≤ 75 km/h	75 < v ≤ 90 km/h	90 < v ≤ 100 km/h	v > 100 km/h	UIC Guideline	Tunnels	DC 1500 V	DC 3000 V	AC 25000 V	ASFA	KVB	BACC	SCMT	PZB	EVM	ETCS L1	ETCS L2	‰ towards NE	‰ towards SW
TARRAGONA - BARCELONA AREA	78	X				X	X		X										X			X				X	45/364	GHE16		X		X								14	13
TARRAGONA - S VICENTE C	25	X				X	X		X										X			X				X	45/364	GHE16		X		X								9	6
S VICENTE C - VILLAFRANCA P	24	X				X	X			X									X			X				X	45/364	GHE16		X		X								14	5
VILLAFRANCA P - MARTORELL	25	X				X	X			X									X			X				X	45/364	GHE16		X		X								14	13
MARTORELL - CASTELLBISBAL	4	X				X	X			X									X			X				X	45/364	GHE16		X		X								1	7
BARCELONA AREA	51	X			X	X	X			X									X			X				X	45/364	GHE16		X		X								15	15
CASTELLBISBAL - MOLLET	25	X			X	X	X			X									X			X				X	45/364	GHE16		X		X						X*		15	15
BARCELONA CAN - RUBI	25	X			X	X	X			X									X			X				X	45/364	GHE16		X		X						X*		15	15
BARCELONA AREA - FRENCH BORDER CLASSIC LINE	150	X					X			X									X			X				X	45/364	GHE16		X		X								15	15
MOLLET - GRANOLLERS	10	X				X	X			X									X			X				X	45/364	GHE16		X		X								12	0
GRANOLLERS - S CELONI	22	X				X	X			X									X			X				X	45/364	GHE16		X		X								15	14
S CELONI - MAÇANET M	19	X				X	X			X									X			X				X	45/364	GHE16		X		X								6	12
MAÇANET M - GERONA	30	X				X	X			X									X			X				X	45/364	GHE16		X		X								10	10
GERONA - FIGUERAS	41	X			X	X	X			X									X			X				X	45/364	GHE16		X		X								15	15
FIGUERAS - PORTBOU	26	X				X	X			X									X			X				X	45/364	GHE16		X		X								15	15
PORTBOU - CERBERE	2	X				X				X									X			X			X		45/364	GHE16	X	X		X	X							0	8
BARCELONA AREA - INTERNATIONAL SECTION MIXED TRAFFIC HIGH SPEED LINE	134	X			X		X									X			X			X				X	45/364	GHE16			X	X						X		18	18
BARCELONA - MOLLET	20	X			X		X									X			X			X				X	45/364	GHE16			X	X						X		18	18
MOLLET - GERONA	76	X			X		X									X			X			X				X	45/364	GHE16			X	X						X		18	18
GERONA - FIGUERAS VILAFANT	34	X			X		X									X			X			X				X	45/364	GHE16			X	X						X		18	18
FIGUERAS VILAFANT - INTERNATIONAL SECTION	4	X			X		X									X			X			X				X	45/364	GHE16			X	X						X		18	18

Figure 4-1 Rail line characteristics in the Barcelona Area.

Rail line characteristics in the Turin Area:

	SECTION LENGHT	LINE TYPE			MAX. TRAIN LENGHT INCL. TRACTION								AXLE LOAD		
	km	PRINCIPAL ROUTE	DIVERSIONARY	CONNECTING/FEEDER	450 m	500 m	550 m	575 m	600 m	625 m	650 m	750 m	20,0 T/axle	21,0 T/axle	22,5 T/axle
MODANE-TORINO	102	X					X								X
MODANE-CONFINE FRANCESE	4	X					X								X
CONFINE FRANCESE-TORINO	98	X							X						X
TORINO-NOVARA	99	X							X						X

	LOAD PER METRE			TRAIN SPEED				LOADING GAUGE		POWER SUPPLY			SIGNALING SYSTEM										GRADIENT	
	6,4 T/m	7,2 T/m	8,0 T/m	v ≤ 75 km/h	75 < v ≤ 90 km/h	90 < v ≤ 100 km/h	v > 100 km/h	UIC Guideline	Tunnels	DC 1500 V	DC 3000 V	AC 25000 V	ASFA	KVB	BEM	BGA	BACC	SCMT	PZB	EVM	ETCS L1	ETCS L2	‰ towards NE	‰ towards SW
MODANE-TORINO			X				X	45/364			X						X	X					30	28
MODANE-CONFINE FRANCESE			X			X		45/364			X						X	X					0	28
CONFINE FRANCESE-TORINO			X				X	45/364			X						X	X					30	0
TORINO-NOVARA			X				X	80/410			X						X	X					14	13

Figure 4-2 Rail line characteristics in the Turin Area.

AII. New Southern Rail Access to the Port of Barcelona – Phase 2

Identifying data of "New Southern Rail Access to the Port of Barcelona – Phase 2 - Connection Works" co-financed by TENT-T [16]:

Identifying data	
Title	New Southern Rail Access to the Port of Barcelona – Phase 2- Connection Works.
Code	INEA/CEF/TRAN/M2014/1057306
Beneficiary	Barcelona Port Authority (APB) y Manager of the Spanish Railway Infrastructure (ADIF).
Management structure	the Ministry of Development and Transport of Spain is the main coordinator of the action, acting as the communication channel between both public entities. The project coordinator is APB with ADIF as a partner, guaranteeing that the action is properly managed in terms of quality, financial management and communication.
Execution	from July 1, 2015 until December 31, 2018 (42 months).
Budget for the Action	total eligible costs: €120,431,565, of which €71,771,463 is financed by the APB and €48,660,102 by ADIF.
Co-financing from the EU	30 % of the eligible costs are financed through the Connecting Europe Facility (CEF) programme: €36,129,469.50; €21,531,438.90 corresponding to the APB and €14,598,030.60 to ADIF

Figure 4-3 New Southern Rail Access to the Port of Barcelona - Data.

AIII. Design parameters for each object of the model

Design parameters for each object on *FlexSim.*

System units: seconds and meters.

- Locomotive:

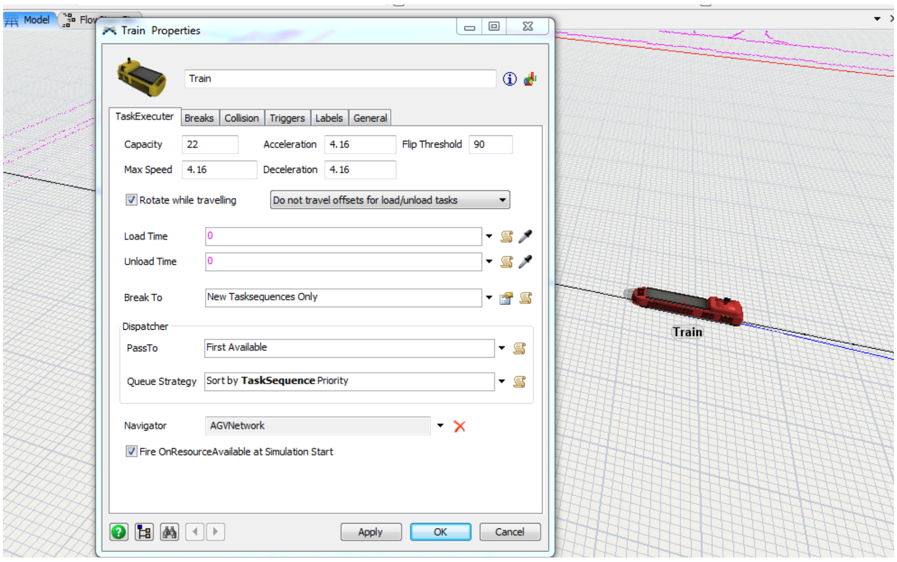


Figure 4-4 Design parameters. Locomotive.

- Waiting Tracks:

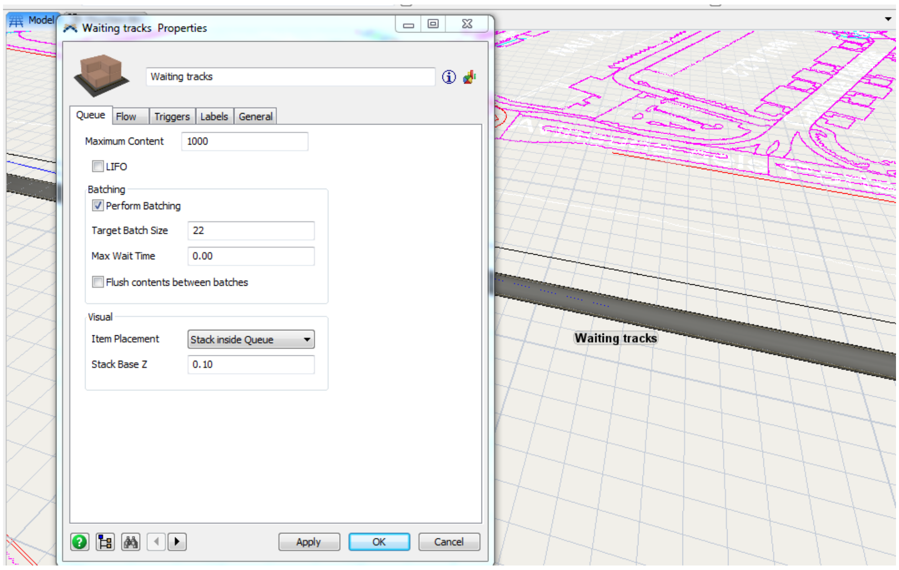
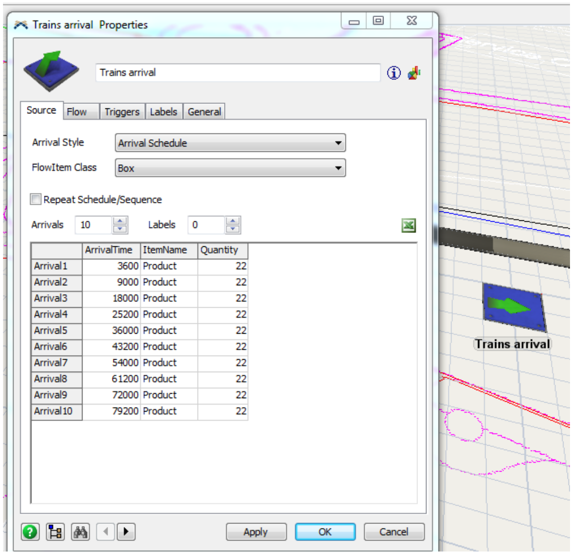


Figure 4-5 Design parameters. Waiting tracks.

- Trains arrival (source):

Scenario 5 trains: Scenario 8 trains:



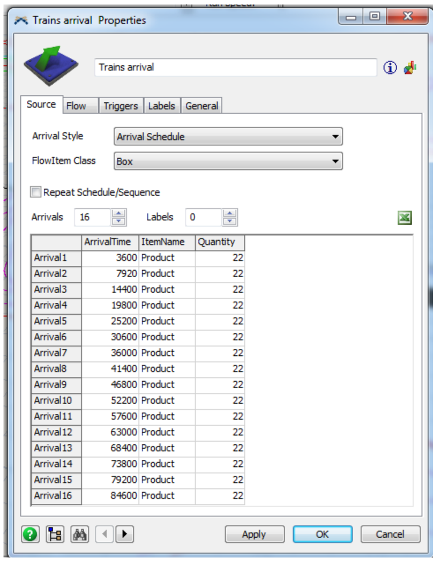
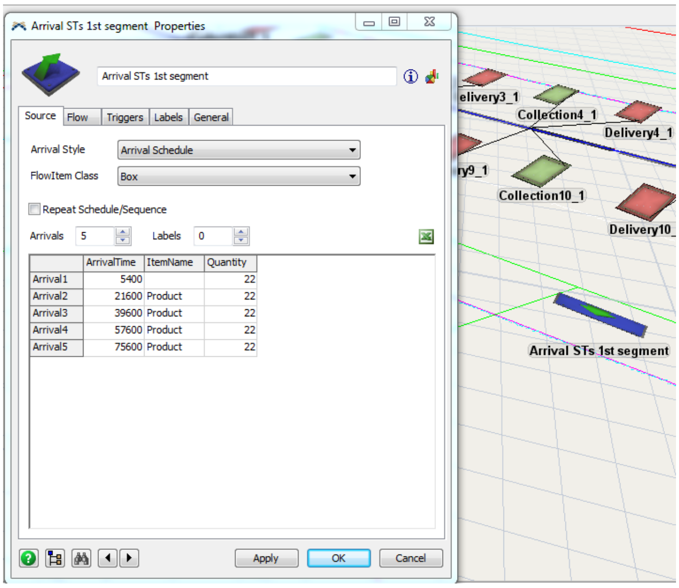


Figure 4-6 Design parameters. Trains arrival (5 and 8 trains per day).

- Trucks arrival (source):

1st segment

Scenario 5 trains: Scenario 8 trains:



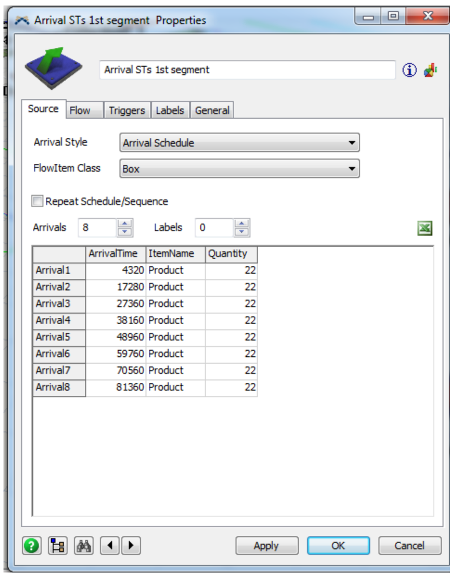
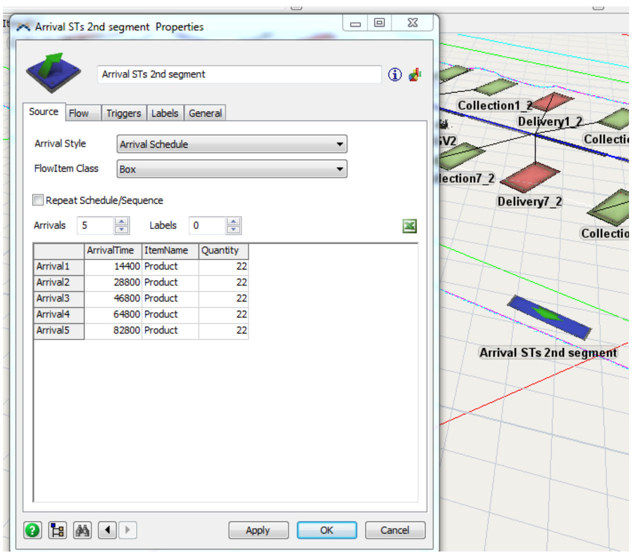


Figure 4-7 Design parameters. Trucks arrival 1st segment (both scenarios).

2nd segment

Scenario 5 trains: Scenario 8 trains:



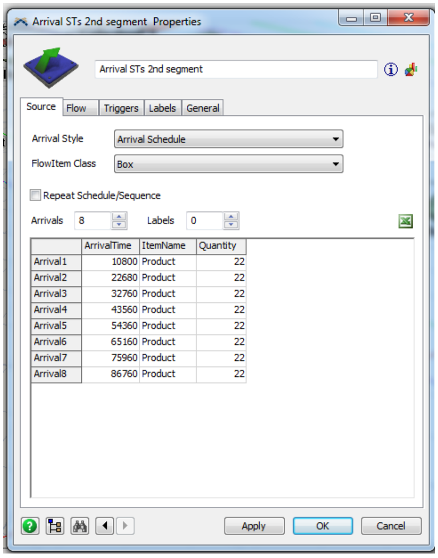


Figure 4-8 Design parameters. Trucks arrival (both scenarios).

- Trucks departure (sink):

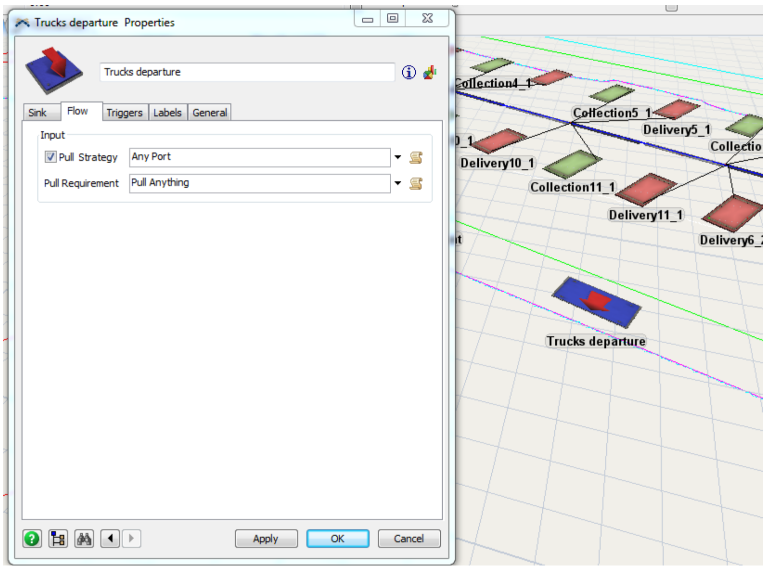


Figure 4-9 Design parameters. Trucks departure.

- Train departure (sink):

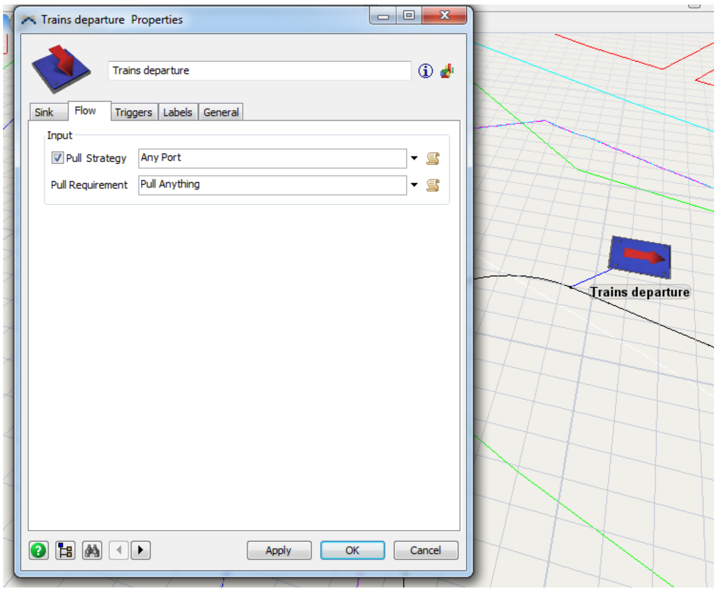


Figure 4-10 Design parameters. Trains departure.

- AGVs (task executer):

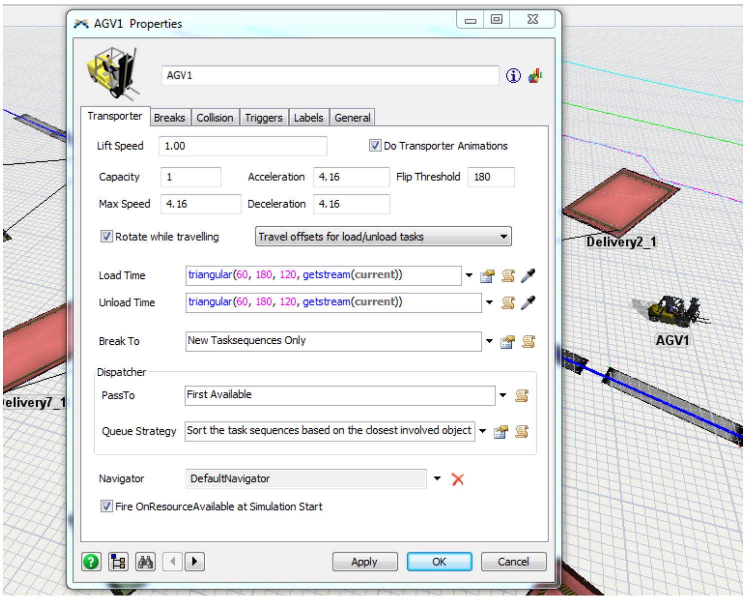


Figure 4-11 Design parameters. AGVs.

- Collection Station (queue):

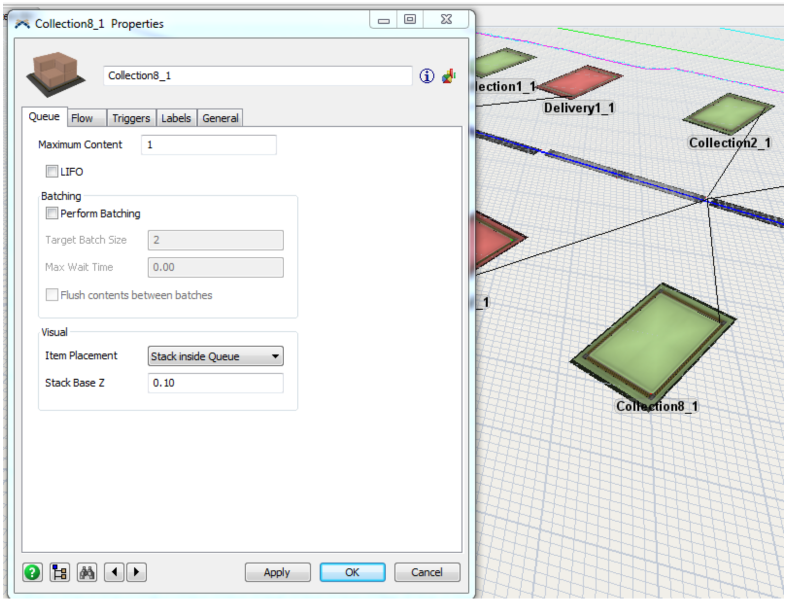


Figure 4-12 Design parameters. Collection stations.

- Delivery Station (queue):

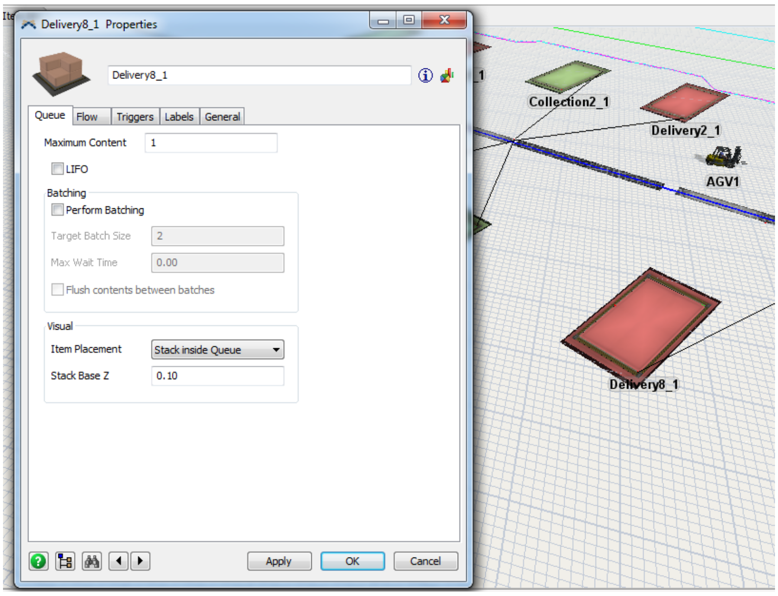


Figure 4-13 Design parameters. Delivery stations.

- Unloading Station (rack):

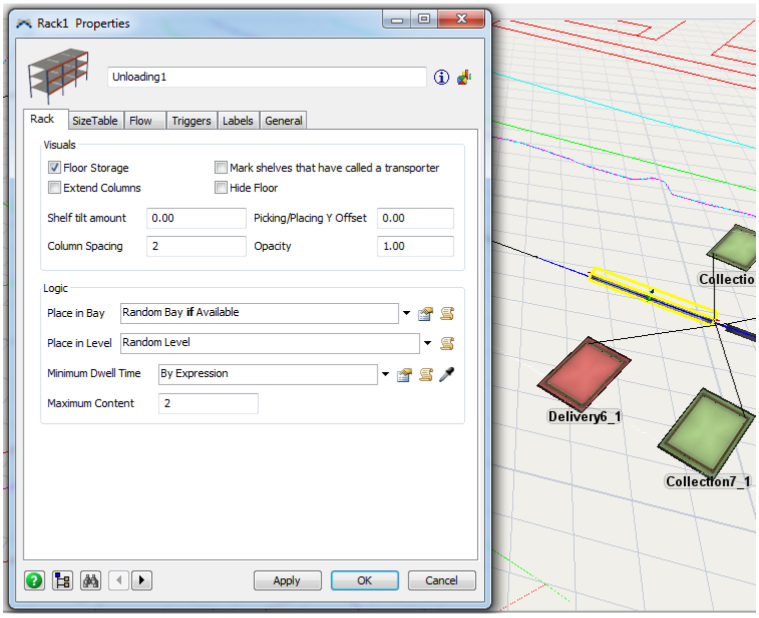


Figure 4-14 Design parameters. Unloading station.

- Loading Station (rack):

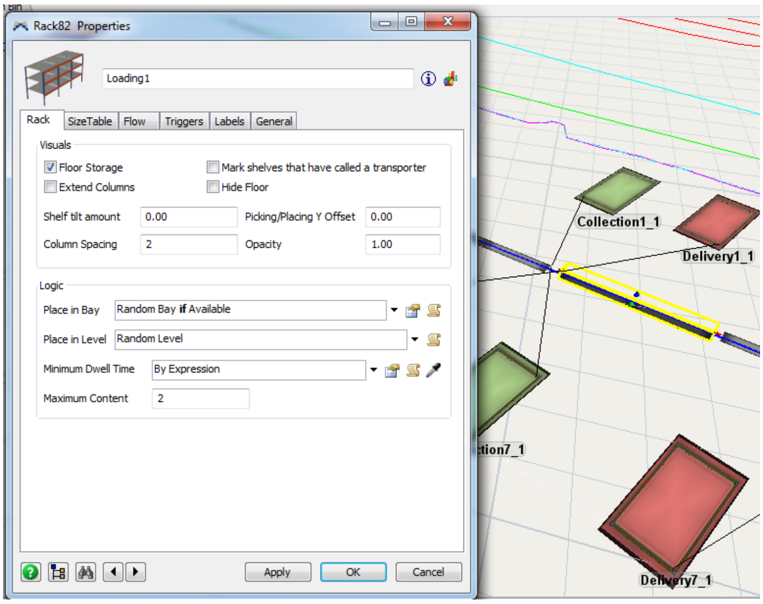


Figure 4-15 Design parameters. Loading stations.

AIV. Detailed simulation statistics for the best scenarios

Simulation statistics for the best scenario simulations:

- 5 trains/day; 3 AGVs

TRAIN by segment	UNLOAD start [s]	UNLOAD finish [s]	LOAD start [s]	LOAD finish [s]	train operation [s]	Unload time [s]	Load time [s]
1 seg1	4030	6293	6290	8486		2263	2196
1 seg2	11383	13585	13580	16550	2897	2202	2970
2 seg1	20401	22400	22400	24427		1999	2027
2seg2	27587	29643	29640	31732	3160	2056	2092
3 seg1	38394	40218	40210	42557		1824	2347
3 seg2	45587	47660	47660	49878	3030	2073	2218
4 seg1	56394	58534	58530	60574		2140	2044
4 seg2	63589	65722	65720	67873	3015	2133	2153
5 seg1	74201	76301	76300	78472		2100	2172
5 seg2	81600	83736	83737	85761	3128	2136	2024
Average [s]					**3046**	**2092,6**	**2224,3**
Average [min]					**50,7**	**34,9**	**37,1**

Table 4-0-1 Simulation statistics for 5 trains/day; 3AGVs.

Comments:

1) train operation average is 3046 s (50,7 min), which is greater than the minimum time of 1800s (30min) between ending operations at segment one and starting operations at segment 2.

2) Average unloading time 34,9min; Average loading time 37,1min.

- 8 trains/day; 5 AGVs

TRAIN by segment	UNLOAD start [s]	UNLOAD finish [s]	LOAD start [s]	LOAD finish [s]	train operation [s]	Unload time [s]	Load time [s]
1 seg1	3940	5445	5445	7090		1505	1645
1 seg2	9450	11002	11002	12533	2360	1552	1531
2 seg1	16019	17607	17607	19316		1588	1709
2seg2	21920	23356	23356	25132	2604	1436	1776
3 seg1	27468	28938	28938	30463		1470	1525
3 seg2	32857	34342	34342	35963	2394	1485	1621
4 seg1	38291	39812	39812	41387		1521	1575
4 seg2	43720	45249	45249	46789	2333	1529	1540
5 seg1	49542	50952	50952	52419		1410	1467
5 seg2	54994	56478	56478	58080	2575	1484	1602
6 seg1	60501	62025	62025	63595		1524	1570
6 seg2	65930	67394	67394	68685	2335	1464	1291
7 seg1	71195	72775	72775	74281		1580	1506
7 seg2	76780	78349	78349	79785	2499	1569	1436
8 seg1	82896	84493	84493	86041		1597	1548
8 seg2	88299	89830	89830	91247	2258	1531	1417
Average [s]					**2419,7**	**1515,3**	**1547,4**
Average [min]					**40,3**	**25,2**	**25,8**

Table 4-2 Simulation statistics for 8 trains/day; 6AGVs.

Comments:

1) train operation average is 2419,7 s (40,3 min), which is greater than the minimum time of 1800s (30min) between ending operations at segment one and starting operations at segment 2.

2) Average unloading time 25,2min; Average loading time 25,8min.